Terrestrial Magnetism

AND

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(Now entitled Journal of Geophysical Research)

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TERRESTRIAL MAGNETISM

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ON DIURNAL VARIATION IN COSMIC-RAY INTENSITY

BY S. E. FORBUSH

Abstract—Cosmic-ray data from precision cosmic-ray meter records obtained at Cheltenham, Maryland, for 273 complete days during April 1935 to October 1936 are subjected to rigorous statistical analysis. The results indicate that the real barometric coefficient does not change from hour to hour or from month to month. It is shown that the barometric coefficient obtained at this station is in good agreement with certain results obtained from altitude-intensity curves. It is furthermore shown, in two independent ways, that there is no indication of any external air-temperature effect upon the recorded intensity. Finally, the data have been subjected to modern statistical methods which provide an objective measure for the probability that the observed diurnal-variation is real. The results indicate, for the period covered by this analysis, a physically significant 24-hour wave in apparent cosmic-ray intensity, with an amplitude of 0.17 per cent of the total intensity having its maximum at about 11^h, 75° west meridian mean time.

Instrument

The data used in this analysis were obtained from meter *C*-1, one of seven precision cosmic-ray meters which were constructed for the Carnegie Institution of Washington Committee on Coordination of Cosmic-Ray Investigations. This meter was designed by A. H. Compton, E. O. Wollan, and R. D. Bennett, and has been adequately described elsewhere[1]. The main ionization-chamber is that which was used in the meter designated as No. 3 in R. L. Doan's paper[2] "Fluctuations in cosmic-ray ionization as given by several recording meters located at the same station." Continuous records have been obtained since April 1935 by the staff of the United States Coast and Geodetic Survey Cheltenham Magnetic Observatory[3] cooperating with the Carnegie Institution's Department of Terrestrial Magnetism. At all times the meter has been fully shielded, the total shielding being equivalent to about 12 cm of pure solid lead[1].

For the total ionization produced within the chamber by cosmic rays alone we use the value 84 ions/cc sec, which was kindly furnished us by Professor A. H. Compton. It was based on results at Chicago in connection with the determination of the residual ionization in each of the seven meters. This is essentially the same as the value 83 ions/cc/sec used by Doan[2].

Barometer-effect

For investigations of the diurnal variation in cosmic-ray intensity the necessity of determining the effect of changes in barometric pressure upon the recorded ionization is well known. This may be done by de-

[1]A. H. Compton, E. O. Wollan, and R. D. Bennett, Rev. Sci. Inst., 5, 415-422 (1934).
[2]R. L. Doan, Phys. Rev., 49, 107-122 (1936).
[3]Latitude 38° 44′ north, longitude 76° 50′ west, elevation above sea-level 72 meters.

termining the correlation between daily mean values of barometric pressure and of ionization, such as is shown graphically in Figure 1. All the

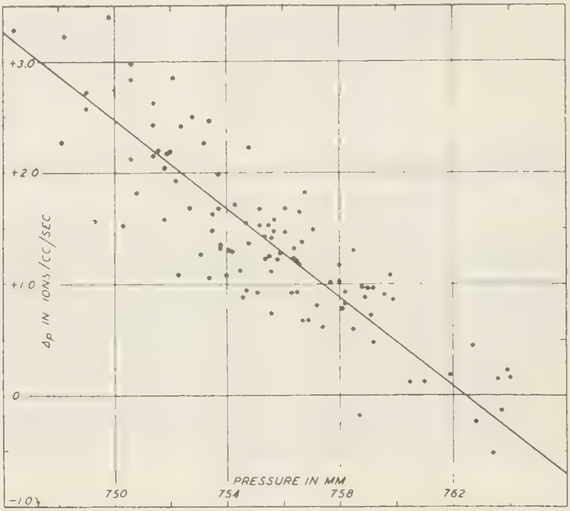

FIG. 1—CORRELATION BETWEEN DAILY MEANS OF BAROMETRIC PRESSURE AND OF DEPARTURE FROM BALANCE (Δ_p), 106 DAYS, JUNE 1—SEPTEMBER 30, 1936

data used throughout this analysis are based upon the observed values of ionization exclusive of "bursts"[2]. We assume, for the ranges in pressure encountered at this station, a linear relation between the observed daily means of barometric pressure, P, and of departures from balance, $\triangle_P$—the instrument automatically[1,2] measures the hourly mean values of the departures from a constant value of ionization—of the form

$$\triangle_{760} = \triangle_P - \beta(P-760) \qquad (1)$$

in which $\triangle_{760}$ is the calculated value of $\triangle_P$ for $P=760$ mm of mercury. If σ_Δ and σ_P be the standard deviations of $\triangle_P$ and P, and r the coefficient of correlation between the latter, then the value of β (usually called the regression-coefficient) given by

$$\beta = r(\sigma_\Delta/\sigma_P) \qquad (2)$$

is that which minimizes[4] the sums of the squares of the differences between the observed and calculated values of $\triangle_P$. In this sense, the value β gives also the best estimate of $\triangle_{760}$. We designate β as the barometric coefficient.

It should be emphasized that the value of β given by (2) is not in general the best value defining the actual relation between P and $\triangle_P$. If, for example, we wish to obtain the best prediction of P, in the sense of least squares, from observed values of $\triangle_P$, we would use[4] the regression-coefficient γ given by

$$\gamma = r(\sigma_P/\sigma_\Delta) \qquad (3)$$

[4]See, for example, Chapter IX, 9th edition, G. U. Yule, Introduction to the theory of statistics Charles Griffin and Co., London, 1929.

that is, the ratio of predicted changes in pressure to the observed changes in $\triangle_P$ should be γ. Thus $1/\gamma$ may be regarded as a second barometric coefficient which one would use to predict P from $\triangle_P$. This is of interest because, in so far as our values of β and γ are correct, it sets an upper and lower limit for the coefficient, which we designate by β_o, expressing the actual relation between $\triangle_P$ and P. The determination of the best approximation to β_o would involve a least-square adjustment in which the proper weights must first be assigned[5] to $\triangle_P$ and P. At any rate, the value β_o must lie between β and $1/\gamma$. Values of r, β, and $(100\ \beta\ 84)$ are given in Table 1 for separate samples and their averages.

TABLE 1—*Correlation-coefficients (r) between daily means of barometric pressure and of cosmic-ray intensity at Cheltenham, Maryland; estimated standard errors (S_r) of r, barometric coefficient (β) expressed as change in rate of ionization in ion cc/sec/mm, estimated probable error (P_β), and percentage-change in ionization per mm of pressure*[a]

Interval	No. days	r	S_r	β	P_β	$100\beta\ 84$
Apr. 20-June 30, 1935	58	−0.88	0.03	−0.209	0.010	−0.249
Aug. 1-Sep. 26, 1935	45	−0.68	0.08	−0.194	0.021	−0.231
Mar. 1-May 19, 1936	73	−0.84	0.04	−0.212	0.011	−0.252
June 1936	28	−0.83	0.06	−0.154	0.013	−0.183
July 1936	25	−0.86	0.05	−0.188	0.015	−0.224
August 1936	31	−0.87	0.04	−0.185	0.013	−0.220
September 1936	22	−0.84	0.06	−0.141	0.013	−0.168
All	282	−0.82	0.02	−0.198	0.006	−0.236
All except Aug. 1-Sep. 26, 1935	237	−0.84	....	−0.198	.....	−0.236

[a]Total ionization due to cosmic rays is 84 ions/cc/sec.

For these r was obtained by measuring the deviations within each sample from the mean of that sample. From the data given in the last row of Table 1, $1/\gamma$ is found to be −0.333 per cent mm of mercury. Consequently β_o, the actual percentage-change in ionization per mm of mercury, should lie between −0.333 and −0.236.

To compare these values with the changes which are actually observed when the same (effectively) instrument is taken to different altitudes we use Figure 4 of A. H. Compton's article[6] "Geographic study of cosmic rays." From the lower portion of the two upper curves (either of which may apply to our station, which is about 40° from the geomagnetic pole) we find values for the percentage-change in the total intensity per mm pressure which are roughly 0.28 and 0.24, respectively. Both values lie within the limits set above for β_o. However, in view of the differences in shielding (12 cm lead for our meter and 5.0 cm lead plus 2.5 cm bronze for the others) this agreement may be somewhat fortuitous.

According to Broxon, Merideth, and Strait[7] the value of barometric coefficient at sea-level, given by ionization-altitude curves obtained by Millikan and Cameron, using an instrument shielded by 7.6 cm of lead plus the 3-mm steel walls, is about 0.21 per cent change in ionization per mm change in pressure.

[5]W. E. Deming, On the application of least squares, Phil. Mag., **11**, 146-158 (1931) and Phil. Mag., **17**, 804-829 (1934).
[6]A. H. Compton, Phys. Rev., **43**, 387-403 (1933).
[7]Phys. Rev., **43**, 687-694 (1933).

Considering the various values of β given in Table 1 together with their estimated probable errors, P_β, there is no strong indication that the differences are real[5]. Indeed, these estimates of the probable errors are somewhat too small on account of the lack of independence between successive daily mean values of $\triangle_P$ (or of P).

Table 2 gives the values of r, β, σ_Δ, σ_P calculated separately from each of the five indicated bihourly means for the same 58 days given in the first row of Table 1. Since each daily mean is the average of 12 such bihourly values, we should expect to find, if these were independent, the standard deviations of the *daily means* to be about $1/\sqrt{12}$ or 0.29 times the standard deviations given in the last two rows of Table 2. Actually σ_Δ and σ_P for the 58 daily means were found to be 0.82 and 3.45, respectively; these values differ little from the corresponding ones for the 58 bihourly means. This indicates that the 12 bihourly values are not independent; in fact, they are almost completely dependent. From this we may infer that the situation is not materially different with respect to the 24 hourly mean values on any given day.

The consequences of overlooking this lack of independence, and applying statistical formulas which are based on the hypothesis of independence, may be serious. We now examine the effect of overlooking this lack of independence upon the values of P_a given by Doan[2] in his Table 1. The differences between the various barometric coefficients a in that Table appear to be roughly 50 times larger than their probable errors. Accepting this, one would conclude that the barometric coefficient was definitely different for each meter, a situation which would be extremely disconcerting since the several meters are identical. Fortunately this is not the case. Using Dr. Doan's equation (6), and the values of P_r, and r given in the Table, we conclude that the value of n used was roughly 700 (the number of hours in the month). Using this value of n together with equations (5) and (6) and the values of r and a from the Table, we find values for P_a which are ten times larger than those in the Table.

After multiplying the values of P_a in the Table by 10, the values of a still appear to be different for the different instruments. Thus far, it is a matter of arithmetic; however, it is evident that the value of 700 (roughly) which was used for n in equations (6) and (7) ignored the fact that the 24 hourly mean values on each of the 31 days were not independent. As our earlier discussion showed, the 24 hourly mean values may for this purpose more safely be taken to be strictly dependent (that is, the same) so that instead of about 700 there are not more than 31 effectively independent values. Thus the values of P_a given in the Table should be roughly 0.2. Even the daily mean values are not strictly independent, so that the value 0.2 may still be somewhat underestimated. For the same reason the values of P_β in our Table 2 are also somewhat underestimated. Rough tests for independence of daily means indicate that our values of P_β (Table 1) might safely be nearly doubled.

Taking these things into account we conclude that the evidence in Table 1 of Dr. Doan's paper does not indicate that the barometric coefficient is different for different meters. From our results (Table 1) we conclude further that there is no good reason for suspecting that the barometric coefficient actually changes from time to time for the same meter. In addition the results indicated in our Table 2 indicate that the

[5]For general remarks on validity of probable errors, see p. 352 of reference footnote 4.

TABLE 2—*Correlation-coefficients (r) between alternate bihourly means of barometric pressure and of cosmic-ray intensity on 58 days during April 20 to June 30, 1935, Cheltenham, Maryland, with standard deviations (σ_Δ and σ_P) of Δ_P and of P* [a]

Bihourly interval	0–2	4–6	8–10	12–14	16–18	20–22
Correlation-coefficient (r)	−0.76	−0.81	−0.81	−0.80	−0.81	−0.78
Barometric coefficient (β) in ion/cc/sec/mm	−0.208	−0.183	−0.194	−0.181	−0.222	−0.195
σ_Δ in ion/cc/sec	0.99	0.86	0.91	0.84	0.98	0.88
σ_P in mm Hg	3.61	3.80	3.79	3.71	3.58	3.52

[a]Estimated standard error (S_r) is about 0.03 in each case and estimated probable error (P_β) is about 0.01 for each β.

barometric coefficient is not significantly different for different hours of the day; this was also indicated by Broxon, Merideth, and Strait.[7]

Although the value of β, based on 282 days of observations, is −0.198 ion/cc/sec/mm of mercury (which corresponds to the line drawn in Fig. 1), we had previously adopted, on the basis of the data then at hand, the value −0.206 ion/cc/sec/mm of mercury. This is the value of β which has been used in all our reductions.

Variations of the second kind and the external temperature-effect

On the basis of −0.206 ion/cc/sec/mm of mercury for β, the daily mean values of ionization corrected to pressure 760 mm of mercury are shown for 317 days in Figure 2. The variations in these daily means

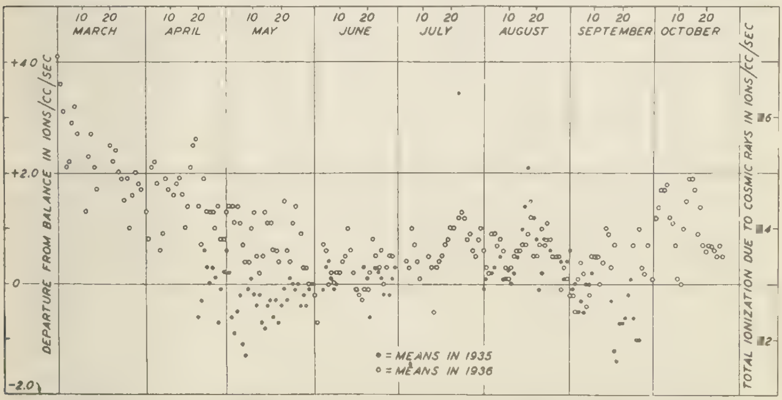

FIG. 2—DAILY MEANS OF APPARENT COSMIC-RAY INTENSITY AT BAROMETRIC PRESSURE 760 MM

have long been termed variations of the second kind. Our present concern is to investigate whether these may be due in part to variations in the temperature of the outside air, as has been reported by Hess and others.[9] As will be shown later, the question of the outside air-temperature effect has an extremely important bearing upon the results of the analysis of the diurnal variation. Indeed in this connection another independent test will be made to determine the magnitude of this effect. For this purpose we assume a linear relation of the form

[9]V. Hess and H. Graziadei, Terr. Mag., 41, 9-14 (1936).

$$\triangle_{P,T} = \triangle_{760} + \beta'(P-760) + \alpha(T-20°.0) \qquad (4)$$

in which $\triangle_{P,T}$ is the observed daily mean departure from balance, and P and T are, respectively, the daily mean values of barometric pressure in mm and of outdoor air-temperature in degrees Centigrade. We determine the constants β' and α in this equation so that the observed values of $\triangle_{P,T}$ are in the best agreement in the sense of least squares, with the values predicted on the basis of the observed pressure and temperature; that is, we determine the constants by least squares assuming the errors of observation are confined solely to the observed values of $\triangle_{P,T}$. The reliability of β' and α is indicated by estimating the probable errors, following the procedure which is described by W. E. Deming in his paper[10] "On the significance of slopes and other parameters estimated by least squares"; that is, the probable errors for each sample are estimated on the assumption that the fit of equation (4) to the data is in each case an average fit.

The results are indicated in Table 3 for several samples. Here it will

Table 3—*Values of coefficients α and β' determined by least squares for formula $\Delta_{P,T} = \Delta_0 + \beta'(P-760) + \alpha(T-20.0)$[a] and of their estimated probable errors*

Interval	No. days	β'	$P_{\beta'}$	α	P_α
		ion cc sec mm		*ion cc sec °C*	
Apr. 20-June 30, 1935	58	−0.208	0.010	+0.012	0.009
June 1936	28	−0.181	0.016	−0.051	0.018
July 1936	25	−0.230	0.016	−0.114	0.025
Aug. 1936	31	−0.175	0.012	+0.051	0.013
Sep. 1936	22	−0.142	.....	−0.006	.....
June-Sep. 1936	106	−0.174	0.007	+0.016	0.009

[a] Δ_0 = departure from balance for P = 760 mm and T = 20°.0 C.

be noted that the values obtained for β' are in agreement with the values of β given in Table 1 for the same sample. Also the values of $P_{\beta'}$ are about the same as those for P_β in Table 1. This indicates that the barometric coefficient derived on the assumption that the observed ionization depends also on outdoor air-temperature is *no more reliable than when derived on the assumption that the observed ionization is independent of outside temperature.*

Finally, the scatter in the values of α, the outside-air temperature-coefficient, calculated from different samples is so great these can not be regarded as real. This is substantiated by the fact that the values of α in each case do not greatly exceed their probable errors. For the same reasons previously discussed in connection with the values of P_β in Table 1, the actual values of P_α (and of $P_{\beta'}$) in Table 3 may be nearly twice as large as those indicated. It is therefore unlikely that a real temperature-coefficient exists, which is greater in absolute value than about 0.02 ion/cc/sec/°C, which corresponds to 0.024 for the percentage-change in total ionization per degree C. Hess[9] has used in some of his reductions a coefficient of −0.09 per cent per degree C (not −0.9 per cent as erroneously printed) when the apparatus was fully shielded but finds

[10] Phys. Rev., 49, 243-247 (1936)—see first paragraph of second column, p. 247.

that with partial (Halbpanzer) shielding the coefficient was so small that no correction for temperature was necessary.

The analysis of the diurnal variation

The adequate characterization of the diurnal variation in any geophysical phenomenon requires not simply a knowledge of its average value but also a full knowledge of its variability. The latter in general is made up of an irregular (or random) part and a systematic part such, for example, as a systematic variation with season in the amplitude (or phase) of the diurnal variation. These facts, together with the methods of analysis used in this discussion, have been set forth clearly in numerous papers by J. Bartels, who, as a research associate for the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, has made important applications to problems in terrestrial magnetism. A great achievement of such methods was the determination of the lunar tide in the Earth's atmosphere at Potsdam. There the semidiurnal lunar wave in atmospheric pressure [11,12] has an amplitude of only 0.01 mm of mercury, and this was determined with a precision of 0.001 mm of mercury from barograms which were read only to the nearest 0.1 mm.

Our raw material for the analysis of the diurnal variation consists for each day of 12 bihourly mean values of the departures from balance ("bursts" deducted). Each of these 12 values is corrected for the corresponding bihourly mean value of pressure in accordance with equation (1), using the value -0.206 ion/cc/sec/mm of mercury for β. The resulting 12 values of departures from balance (for $P = 760$ mm) are subjected to harmonic analysis, providing a set of harmonic constants a_1, b_1, a_2, b_2 for each day[13]. Following Bartels[14], the 24-hour wave for each day is completely characterized by a point, with coordinates a_1 and b_1, in a Cartesian diagram. This point may be considered the end-point of a clock-hand, which indicates the time of the wave-maximum on a suitable 24-hour dial, and the length of which indicates the amplitude of the wave. Such a diagram is called the 24-hour harmonic dial[14]. Similarly a 12-hour harmonic dial is constructed in which the time indicated by the hand (on the 12-hour dial) is that of the first maximum. For N days we have in each dial a cloud of N points and the analysis of the variability of the diurnal variation is now transformed into an analysis of the geometrical properties of these clouds[11].

The two-dimensional Gaussian frequency-distribution which fits the cloud best is in general elliptical, that is to say, the lines of equal frequency are ellipses. We need here only the expression for the axes of the *probable ellipse*, that is, the ellipse which contains $(N/2)$ points inside and $(N/2)$ points outside. The lengths P_1 and P_2 of the major and minor axes of the *probable ellipse* are given[14] by

$$P_1 P_2 = 0.833\sqrt{(\sigma^2_{a_1} + \sigma^2_{b_1}) \mp \sqrt{(\sigma^2_{a_1} - \sigma^2_{b_1})^2 + 4r^2\sigma^2_{a_1}\sigma^2_{b_1}}} \qquad (5)$$

in which σ_{a_1} and σ_{b_1} are the standard deviations of a_1 and b_1 from their

[11] J. Bartels, Sci. Mon., **35**, 110-130 (1932).
[12] J. Bartels, Berlin. Abh. Met. Inst., **8**, No. 9, 1-51 (1927); Abstract in Naturw., **15**, 860-865 (1927).
[13] a_3, b_3 were also determined but are not included in this discussion.
[14] J. Bartels, Terr Mag., **37**, 291-302, (1932).

respective means and r is the coefficient of correlation between the N values of a_1 and b_1. In case of circular symmetry $P_1 = P_2 = 0.833M$ in which $M = \sqrt{\sigma^2_{a_1} + \sigma^2_{b_1}}$. Similar expressions hold also for the cloud in the 12-hour dial.

The last line of Table 4 gives the constants for the 24-hour dial for

TABLE 4—*Constants for 24-hour harmonic dial of apparent cosmic-ray intensity in ionization-cham*[...] *Cheltenham, Maryland, April 1935 to October 1936*

Sample	Interval	No. days	Average[a] a_1	Average[a] b_1	Average[a] c_1	t_{max} 75°WMT	Standard deviation σ_{a_1}	Standard deviation σ_{b_1}	M (σ … σb
			ion/cc/sec			*h*	*ion/cc/sec*		
A	Apr. 20-June 30, 1935..	58	−0.169	+0.075	0.185	9.4	0.188	0.196	0.
B	Mar. 1-May 31, 1936..	82	−0.122	−0.046	0.130	12.4	0.210	0.204	0.
C	June 1-July 31, 1936...	53	−0.163	+0.060	0.174	9.7	0.199	0.202	0.
D	Aug. 1-Sep. 17, 1936...	48	−0.147	+0.007	0.147	10.8	0.203	0.202	0.
E	Sep. 24-Oct. 27, 1936...	32	−0.107	−0.060	0.123	13.0	0.233	0.273	0.
All samples		273	−0 142	+0 008	0 142	10 8	0.206[b] 0 206[c]	0.217[b] 0 213[c]	0 0.
All samples without correction for non-cyclic change........		273	−0.145	+0.015	0.146	10.6	0.207[b]	0.248[b]	0.

[a] a_1 and b_1 positive upward and to right from origin, respectively, along axes 23[h] and 5[h].
[b] When departures are from mean of all samples.
[c] When departures in each sample are from mean of that sample.

273 days when no correction for non-cyclic change was applied. For this case $\sigma_b > \sigma_a$ and the distribution is slightly elliptical; the axes of the ellipse were found to be in the ratio 1:1.26. After the coefficients a_1 and b_1 for each day were corrected for the apparent linear non-cyclic change[15] it will be seen from Table 4 that the value of σ_b was reduced by about 15 per cent, the ratio of the axes of the probable ellipse becoming 1.00. This is interpreted as justifying the correction for non-cyclic change, particularly since the presence of any variable linear non-cyclic change in the data would affect the coordinate b about four times[15] as much as a. The values in Table 4 refer then, except as otherwise noted, to values of a and b, which have been corrected for non-cyclic change, in which case the probable ellipse is a circle—called the probable-error circle. Incidentally, the coefficients have all been corrected for the use of bihourly means[16].

Figure 3 shows the points in the 24-hour harmonic dial for 273 single days which make up the five samples indicated in Table 4. The center of the cloud coincides with the center of the small circle. The large circle is the probable-error circle for single days. Its radius[14] is $0.833M = 0.250$ ion/cc/sec. The number of points inside the circle is 138, very closely half the total number of points. If now the points for successive days are independent, then the radius of the probable-error circle for the mean of 273 days should be $0.250/\sqrt{273} = 0.0152$. The actual amplitude,

[15] C. C. Ennis, Terr. Mag., 32, 155-162 (1927).
[16] J. Bartels, Terr. Mag., 40, 1-60 (1935).

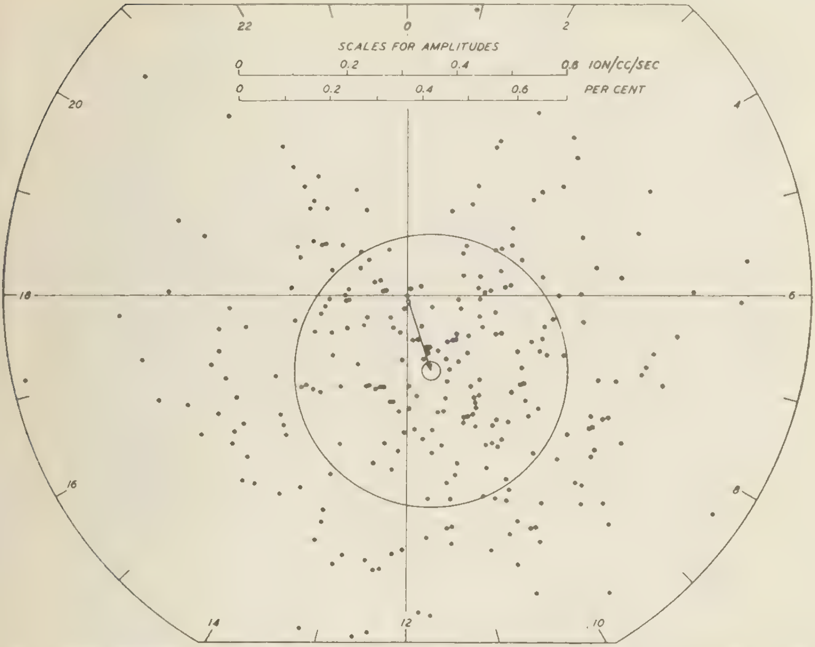

FIG. 3—24-HOUR HARMONIC DIAL, APPARENT COSMIC-RAY INTENSITY, 273 SINGLE DAYS DURING APRIL 20, 1935 TO OCTOBER 27, 1936, CHELTENHAM, MARYLAND (TIMES OF MAXIMUM IN 75° WEST MERIDIAN MEAN HOURS)

C_1, from Table 4 is 0.142, which is about 9.3 times the radius of the probable-error circle. Therefore, the probability that the mean of another such sample of 273 days should by accident fall outside a circle of radius 0.142 with its center at the mean of the observed cloud is $(1/2)^{(9.3)^2}$ or only about 10^{-26}.

Another criterion for the physical significance of the observed amplitude is through equations (17.4), (17.6), and (19.1) of Bartels' discussion of the random walk[1h]. For $M = 0.300$ (Table 4), $C_1 = 0.142$ (Table 4), $l = 0.332$ (Bartels' equation 19.1), and $n = 273$, we have $m = 0.0201$ and $\kappa^2 = 50.0$. From Bartels' equation (17.6) the probability that our observed amplitude 0.142 is the result of accident is $W(\kappa) = 10^{-21}$. Unless the 273 days are strictly independent, the estimate in the preceding paragraph for the radius of the probable-error circle is too small. The result of the test for independence is shown in Figure 5. The upper line, determined by the equation $M(h) = 0.300/\sqrt{h}$, shows how the value of M for means of h successive days should depend on h, *if the successive days were independent*. The calculated values of $M(h)$ for means of 4, 8, 12, 16, and 24 successive days are indicated by the circles; since their accuracy is only of the order $1/\sqrt{2h}$, there is no indication of lack of independence in the sample of 273 days. Thus it is practically certain that **the 24-hour wave in *apparent* cosmic-ray intensity is real.**

The 12-hour harmonic dial (constants in Table 5) is shown in Figure

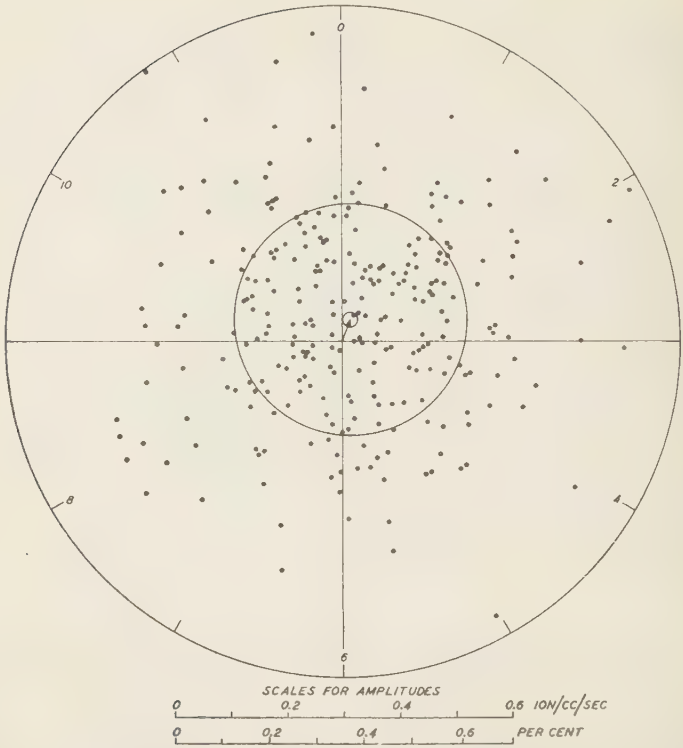

FIG. 4—12-HOUR HARMONIC DIAL, APPARENT COSMIC-RAY INTENSITY, 273 DAYS DURING APRIL 20, 1935, TO OCTOBER 27, 1936, CHELTENHAM, MARYLAND (TIMES OF FIRST MAXIMUM IN 75° WEST MERIDIAN MEAN HOURS)

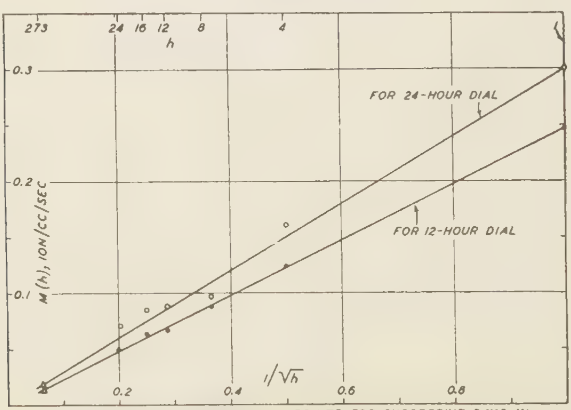

FIG. 5—TEST FOR INDEPENDENCE OF POINTS FOR SUCCESSIVE DAYS IN 24-HOUR AND 12-HOUR HARMONIC DIALS, APRIL 20, 1935, TO OCTOBER 27, 1936, CHELTENHAM, MARYLAND

4 together with the probable-error circles (the ratio of the axes of the ellipse, that is, P_1/P_2 was in this case actually 1.05) for single days and for the mean. As before, the number of points inside the former circle is not very different from the number outside. The lower part of Figure 5 shows the results of the test for independence of successive days in the 12-hour dial. As before, there is no indication of any lack of independence. Using the value of 0.246 given for M_2 in Table 5 the radius of the probable-error circle for the mean is $0.833 \times 0.246/\sqrt{273} = 0.0124$. The actual amplitude C_2 from Table 5 is 0.042, which is about 3.4 times the radius of the probable-error circle. The probability that the mean of another such sample of 273 points should fall by accident outside the circle which passes through the origin and the center of which is at the center of the observed cloud is $(1/2)^{3.4^2}$ or about one in 3000. Using the results of the random walk as above the probability for the observed amplitude being the result of accident is about one in 2000. Thus there may be a physically real 12-hour wave in the data considered, but more data are required to demonstrate it with a convincingly high degree of probability.

The points in the 12-hour dial obtained for the means of different

BLE 5—*Constants for 12-hour harmonic dial of apparent cosmic-ray intensity in ionization-chamber, Cheltenham, Maryland, April 1935 to October 1936*

le	Interval	No. days	Average[a]			t_{max} 75°WMT	Standard deviation		$M_2 = (\sigma_{a_2}^2 + \sigma_{b_2}^2)^{1/2}$
			a_2	b_2	c_2		σ_{a_2}	σ_{b_2}	
			ion/cc/sec			*h*	*ion/cc/sec*		
	Apr. 20-June 30, 1935..	58	+0.048	+0.018	0.051	11.7	0.168	0.162	0.234
	Mar. 1-May 31, 1936..	82	+0.026	+0.031	0.040	0.7	0.179	0.192	0.262
	June 1-July 31, 1936...	53	+0.055	+0.049	0.074	0.4	0.166	0.185	0.249
	Aug. 1-Sep. 17, 1936...	48	−0.027	+0.015	0.031	4.0	0.162	0.162	0.224
	Sep. 24-Oct. 27, 1936...	32	+0.038	+0.045	0.059	0.7	0.158	0.165	0.228
ll samples		273	+0.028	+0.031	0.042	0.6	0.171[b]	0.176[b]	0.246[b]

$_2$ and b_2 positive upward and to right from origin, respectively, along axes 11^h and 2^h.
tandard deviations of departures are measured from mean of 273 days.

samples in Table 5, together with the mean of all the samples and its probable-error circle are shown in Figure 8. The points for the 12-hour wave in pressure are also indicated.

The effect of the corrections for barometric pressure, and its uncertainty, upon the resultant 24-hour wave

Figure 6 shows the effect of the corrections for barometric pressure on the 24-hour wave in apparent cosmic-ray intensity. C is the point, for apparent cosmic-ray intensity, in the 24-hour dial for the mean of 273 single days. P is the point representing the average 24-hour wave in barometric pressure (without any correction for non-cyclic change) for the same 273 days. On account of the additive property[16] of harmonic coefficients (that is, the principle of superposition) the vector

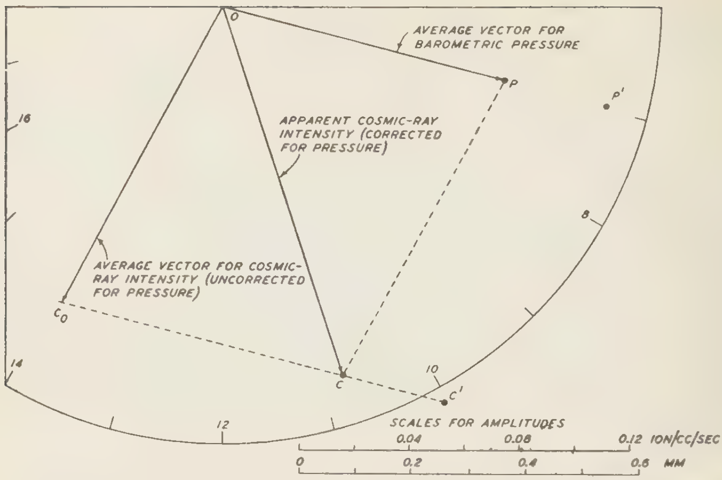

FIG. 6—24-HOUR HARMONIC DIAL SHOWING EFFECT OF PRESSURE-CORRECTIONS ON AVERAGE 24-HOUR WAVE IN APPARENT COSMIC-RAY INTENSITY, 273 DAYS DURING APRIL 20, 1935 TO OCTOBER 27, 1936, CHELTENHAM, MARYLAND (TIMES OF MAXIMUM IN 75° WEST MERIDIAN MEAN HOURS)

OC may be conceived as the resultant of OP and another, OC_o. Thus C_o is the point in the harmonic dial which would have been found had no corrections for pressure been applied to the raw data. This shows that the actual 24-hour wave found in the data can not possibly be the result of the corrections applied for pressure. As far as its effect on OC is concerned, the effect of an error in the adopted value of the pressure-coefficient β amounts to an increase or decrease in the length OP. Thus, if the value 0.33 per cent per mm, which was the upper limit for β_o, had been adopted, the point C would have been shifted to C'. Therefore, the position of C, which would result from using the actual (unknown) value β_0 for the barometric coefficient, is practically confined to the line segment CC' in Figure 6.

Corrections for barometric pressure were applied before making the harmonic analysis. As far as the average wave is concerned, the same result would have been found had the harmonic analysis been made first and the corrections for pressure then applied. However, the scatter of points in the dial for the 24-hour wave of apparent cosmic-ray intensity, uncorrected for pressure, would certainly have been greater and consequently the apparent probability for reality enormously smaller. This follows from the fact that the scatter in the 24-hour dial for barometric pressure derived from all days[17] is, relative to the average amplitude for all days, probably greater than the relative scatter found in the 24-hour dial for apparent cosmic-ray intensity corrected for pressure.

Comparison of results from different samples, including some tests for the effect of temperature on the instrument

Points in the 24-hour dial for different samples, designated in Table 4, are shown in Figure 7, together with their respective probable-error

[17]See, for example, Tables 6 and 19 of reference in footnote 12 for Potsdam results; also J. Bartels, Wien-Harms, Handbuch der Experimentalphysik, 25, I, 163-210 (1928).

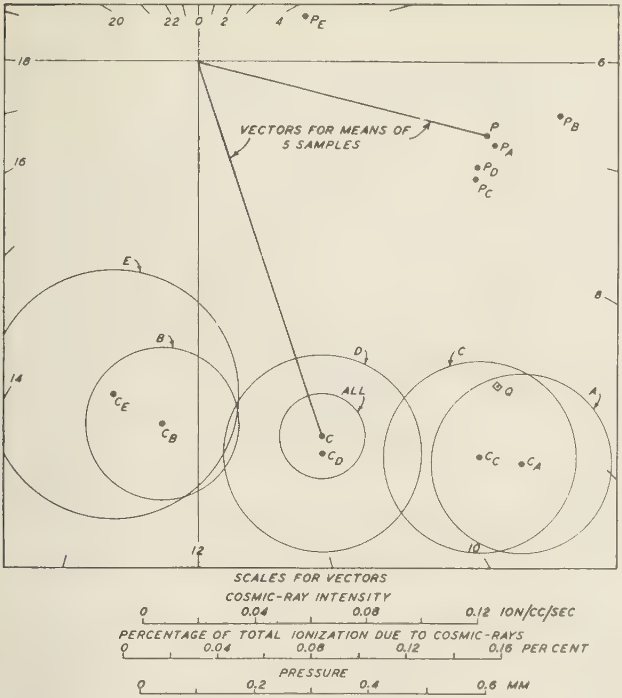

FIG. 7—24-HOUR HARMONIC DIAL, MEANS OF SEPARATE SAMPLES FOR APPARENT COSMIC-RAY INTENSITY (C) AND FOR BAROMETRIC PRESSURE (P), APRIL 20, 1935 TO OCTOBER 27, 1936, CHELTENHAM, MARYLAND (TIMES OF MAXIMUM IN 75° WEST MERIDIAN MEAN TIME)

circles. Samples A, C, and D were obtained with the instrument operating under nearly the same conditions of temperature. During these periods the instrument was subjected to a quite regular diurnal-variation of temperature with a maximum at 24^h and an amplitude of about 0°.5 C (on account of the insulation of the room). For the sample B the room was, for 62 out of the 82 days, kept at constant temperature by thermostatic control. Sample E was secured with the door to the insulated room opened to an adjacent uninsulated room; under these circumstances the variations in temperature in the meter-room were somewhat irregular but the diurnal variation was, on the average, about 2° C with the maximum near 17^h. Now because the value of $M = \sqrt{\sigma^2_a + \sigma^2_b}$ (see Table 4), derived when the departures of a and b were from the mean of all the samples, was so little different from the value of M obtained[18] when the departures within each sample were from the means for that sample, no very significant difference between the means of the different samples was to be expected. The probability that any two samples are separated a distance $K\sqrt{\rho^2_1 + \rho^2_2}$ by chance[14] is $(1/2)^{K^2}$ where

[18]By application of equations (67) and (68) of W. E. Deming and Raymond T. Birge, Statistical theory of errors, Rev. Mod. Phys., 6, 119-161 (1934).

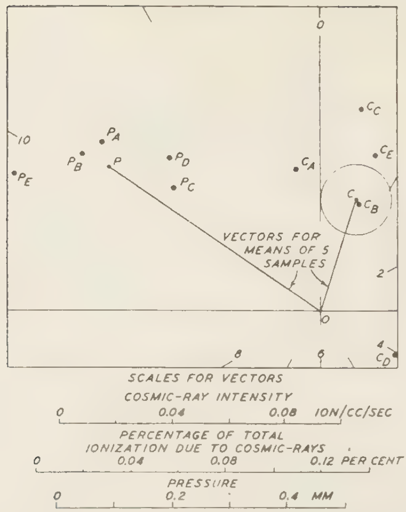

FIG. 8—12-HOUR HARMONIC DIAL, MEANS OF SEPARATE SAMPLES FOR APPARENT COSMIC-RAY INTENSITY (C) AND FOR BAROMETRIC PRESSURE (P), APRIL 20, 1935 TO OCTOBER 27, 1936, CHELTENHAM, MARYLAND (TIMES OF MAXIMUM IN 75° WEST MERIDIAN MEAN HOURS)

ρ_1 and ρ_2 are the radii of the two probable-error circles. In this way it is found that the probability that any sample is separated from the mean of all the samples by chance, is greater than one-eighth in all cases. Thus no sample differs significantly from the mean of all samples. The probability for separation by chance is least for the samples A and B and is for this case 1/500 which is not small enough to be definitely significant. Therefore, this test indicates that the instrument is not affected by changes in temperature.

The point Q of Figure 7 is the result reported by Doan[2] referred to the same local-time origin as for the data at Cheltenham. Doan's paper does not indicate the value of barometric coefficient used in his reduction or the average diurnal-variation of barometric pressure on the ten days. It certainly may not be safely assumed that a series of observations with five instruments on ten days is equivalent to a series with one instrument for 50 days. This would depend on how much the scatter in the harmonic dial was due to external causes common to the five instruments. In any case Doan's results for Chicago are in accord with those for Cheltenham which is additional evidence that the Cheltenham meter has no temperature-effect since it is most unlikely that the five instruments at Chicago were subjected to the same diurnal-variation in temperature as the one at Cheltenham.

Additional tests for external temperature-effect

The results of additional tests for external temperature-effect are shown in Figure 9. C_1 and C_2 are the mean points in the 24-hour dial for apparent cosmic-ray intensity on two groups of days, with their probable-

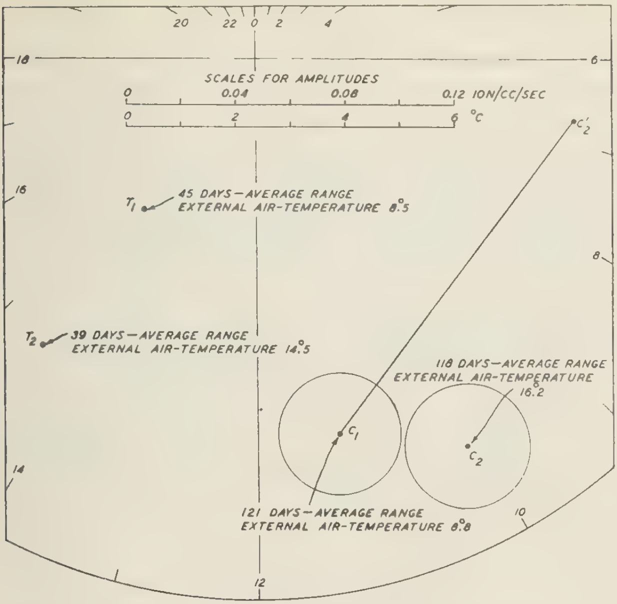

FIG. 9—24-HOUR HARMONIC DIAL, EFFECT OF TEMPERATURE EXTERNAL AIR ON APPARENT COSMIC-RAY INTENSITY, APRIL 20, 1935 TO SEPTEMBER 27, 1936, CHELTENHAM, MARYLAND (TIMES OF MAXIMUM IN 75° WEST MERIDIAN MEAN HOURS)

error circles. C_1 is for 121 days on which the average range in outdoor air-temperature was 8°.8C and C_2 is that for 118 days with an average range of 16°.2C. For group C_1 no daily range was greater than 12° C and for group C_2 no daily range was less than 12° C. T_1 and T_2 of Figure 9 represent the 24-hour wave in external air-temperature for averages of 45 and 39 days on which the average ranges in temperature were 8°.5 C and 14°.5 C, respectively. These days were taken from the two groups used for C_1 and C_2 and may be safely assumed to represent closely the diurnal variations in temperature for days to which C_1 and C_2 correspond. Were there any appreciable external temperature-effect, then it is to be expected that C_1 and C_2 would be definitely separated; the probability that the observed separation is due to chance is one in four. On the assumption of an external temperature-effect of -0.055 per cent of the total intensity per degree Centigrade, we should expect to find the point C_2 at C_2' and the probability of C_2 being so separated by accident from C_1 would be one in 10^6; thus were there a temperature-effect as great as that postulated, there certainly should be some indication of it. Hence this test supports the previous conclusions that there is no effect because of external temperature.

Comparison with other results and effect of local radiation

Hess and Graziadei[9] find, using an external temperature-coefficient of -0.09 per cent per degree Centigrade, a 24-hour wave which, on the

basis of local time, agrees closely in phase and amplitude with that for Cheltenham for which no corrections for external temperature were applied. The former results were also in agreement with those obtained at Innsbruck by Steinmaurer[19] using the same external temperature-coefficient. However, when no correction for external air-temperature is applied to Steinmaurer's data, the maximum of the 24-hour wave occurs about 6^h L.M.T. This is probably also true for Hess's[9] data. Unless there is some definite reason why an external temperature-effect appears to exist at Innsbruck and on the Hafelekar but not at Cheltenham, it is evident that the results for the 24-hour wave at the last station are not in agreement, on the basis of local time, with those from the other stations.

Recently, at the Department of Terrestrial Magnetism, G. R. Wait has obtained results indicating the possibility of a diurnal variation of ionization in the air due to gamma rays alone; its amplitude may amount to as much as 0.3 ion/cc/sec in air, with the maximum about noon. In passing through 12 cm of lead the intensity of gamma rays may be expected to be reduced to about 0.25 per cent of the initial value (assuming the rays arise from radium *C*). Since the ionization produced by these within the chamber of the meter at Cheltenham should be about 67 times[1] greater than for normal air, a diurnal variation with amplitude as great as 0.05 ion/cc/sec in the chamber would be expected at Washington. This is about one-third the amplitude of the observed diurnal variation in apparent cosmic-ray intensity at Cheltemham. Any diurnal variation in gamma rays may vary with locality and thus distort determinations of the actual diurnal variation in cosmic-ray intensity.

To summarize, this analysis of the data for Cheltenham demonstrates the existence of a physically real 24-hour wave in apparent cosmic-ray intensity, which does not appear to be due to systematic instrumental effects but which may be due, in part at least, to variations in local radiation. It is hoped some statistical tests may be made to determine, if possible, whether the diurnal variation in the Earth's magnetic field may, as suggested by Gunn[20], be responsible for the apparent diurnal-variation.

Thanks are due the personnel of the Division of Terrestrial Magnetism and Seismology of the United States Coast and Geodetic Survey and particularly its staff at the Cheltenham Magnetic Observatory, whose generous cooperation makes possible the cosmic-ray records herein discussed. The writer wishes to acknowledge his indebtedness to Dr. J. A. Fleming, Director of the Department of Terrestrial Magnetism, for having made the investigation possible and for his continued interest in it.

[19]Beitr. Geophysik, **45**, 148-183 (1935).
[20]R. Gunn, Phys. Rev., **41**, 683 (1932).

DEPARTMENT OF TERRESTRIAL MAGNETISM,
CARNEGIE INSTITUTION OF WASHINGTON,
Washington, D. C., December 8, 1936

SHORT-TIME MAGNETIC FLUCTUATIONS OF LOCAL CHARACTER*

By Victor Vacquier

Abstract—The comparison of the short-time fluctuations of the Earth's vertical magnetic intensity afforded by data taken during the daylight hours by the exploration troops of the Gulf Research and Development Company indicates that at points separated by 800 miles, 58 per cent of the fluctuations are of local origin. It is found that on a few magnetically quiet days, the time-variations of the vertical magnetic intensity are locally so different in magnitude and in phase, as to condemn the theories of magnetic variations which are based solely upon the difference between night- and day-ionization of the upper atmosphere. The observed irregularities are independent of magnetic activity. They can be accounted for only by the dynamo-theory, and indicate the presence of local air-circulations in the ionosphere. It is suggested that simultaneous registration of the magnetic elements at points spaced about five times the ionospheric height might delineate the circulation of the upper air, and thus provide perhaps information useful to meteorology.

A study of short-time fluctuations of the Earth's magnetic field has been heretofore largely confined to the analysis of average curves constructed from observatory-data. It is generally believed that although the amplitude and the phase of magnetic variations may differ considerably for successive quiet days, they are very nearly identical on the same day at neighboring points, say five degrees of longitude apart. It is pointed out in treatises on terrestrial magnetism that the variations of the magnetic elements are regular and widespread in contrast with the changes suffered by meteorological elements such as temperature and pressure of the air. Although undoubtedly the meteorological elements are locally more disturbed, one cannot help wondering whether the regularity so characteristic of magnetic variations is not partially due to dearth of data and to the smoothing effect of averaging what data there are over many days.

That on magnetically quiet days local magnetic variations of substantial amplitude actually exist, especially in the vertical component, is apparent from inspection of observatory-data. Occasionally at one observatory the difference in time between the occurrence of the diurnal minima of the vertical intensity on two consecutive days can vary from 20 to 29 hours. Furthermore, it is observed that on the same day these departures from diurnal periodicity may not be exhibited at other observatories and are, therefore, purely local. This is illustrated by Figure 1, on which the tabular values for the vertical magnetic intensity at Cheltenham and at Tucson, published by the United States Coast and Geodetic Survey, are plotted for four selected groups of two consecutive days. The first group of curves for April 26 and 27, 1925, shows that the minima at Tucson are separated by 25 hours, while the minima at Cheltenham are separated by only 20 hours. On the other hand, on June 11 and 12 of the same year, the minima at Cheltenham were 29 hours apart while at Tucson they occurred again at an interval of 25 hours. This possible difference of nine hours in the occurrence of diurnal minima indicates that magnetic fluctuations exhibit local features on the same day. An investigation of the differences between the magnetic fluctuations at various places when referred to local time, is apt to throw some additional light on the physical processes generating the disturbances and perhaps provide a test for the existing theories of the diurnal variation of the Earth's magnetism.

*Published by permission of Dr. P. D. Foote, Executive Vice-President of the Gulf Research and Development Company, Pittsburgh, Pa.

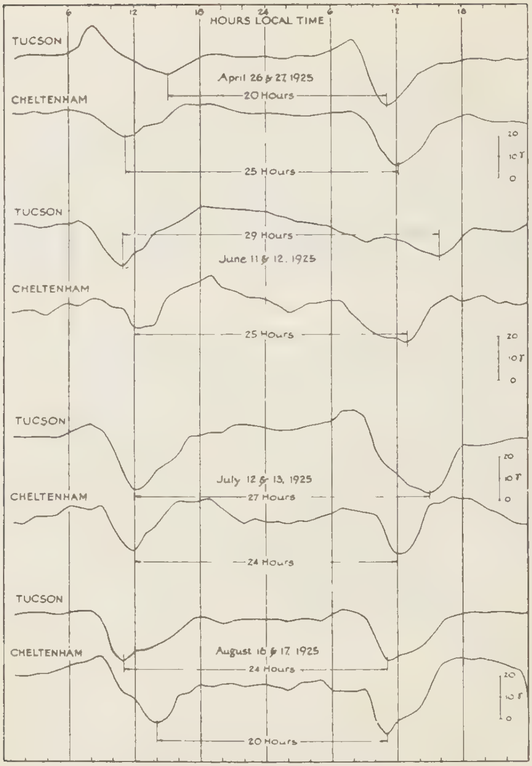

FIG. 1—DIFFERENCES IN TIME OF DIURNAL MINIMA OF VERTICAL MAGNETIC INTENSITY ON CONSECUTIVE DAYS AT CHELTENHAM AND TUCSON

The magnetic data taken by the exploration-troops of the Gulf Research and Development Company offered a splendid opportunity for such a study. Each troop was equipped with a vertical-intensity Schmidt balance of Askania make which was kept stationary and which was read at ten-minute intervals during the hours the troop was in the field. Its sensitivity was three gammas per scale-division or 1.2 gammas per minute deflection of the magnet-system. The instruments were very carefully adjusted, so that the probable error of field-observations and, therefore, also of the diurnai-variation measurements, was about one gamma. The technique by which this precision was secured has little bearing on the subject of this paper and will not be discussed. At the beginning and at the end of each day's work the variometers belonging to one troop were compared with the stationary instrument by simultaneous readings. If a discrepancy greater than 2.5 gammas occurred between the comparisons morning and evening, the data were rejected.

The average locations of the troops are designated on the map of Figure 2 by Roman numerals. At the present time the means for making an absolute determination of the vertical intensity in the field with suf-

ficient precision are lacking so that no base-line values were determined and only a relative comparison of the diurnal curves could be made. To compare two diurnal curves taken on the same day at two different

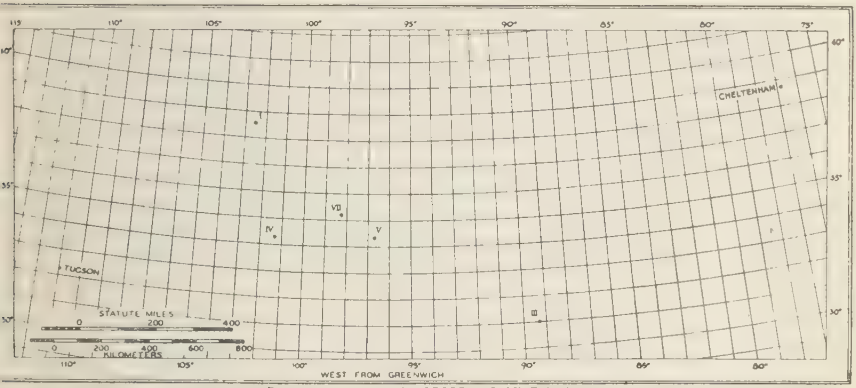

FIG. 2—LOCATION OF OBSERVING STATIONS

stations, the curves were read every half-hour of local time and subtracted. The average difference for the day was then subtracted from each half-hourly difference. The resultant curve thus represents the residuals obtained by subtracting the diurnal curves after shifting them

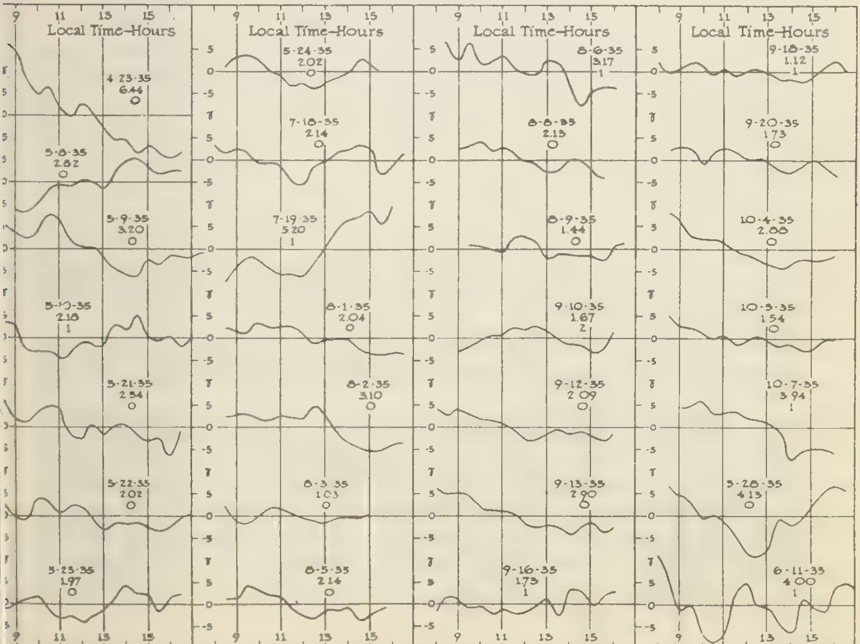

FIG 3—DIFFERENCES IN VARIATIONS OF VERTICAL MAGNETIC INTENSITY AT STATIONS IV AND V—SEPARATION 260 MILES

vertically so that their average ordinates were made to coincide. Figure 3 shows 28 such difference-curves picked out at random from the total number of 41 obtained from the comparison of diurnal-variation curves observed simultaneously at locations *IV* and *V*. The numbers under the dates express the means of the absolute values of the half-hourly ordinates. The magnetic character-figure 0, 1, or 2 was supplied from the Tucson Observatory. Inasmuch as the separation of the points of observation was only 260 miles, it is rather striking that departures as great as 20 gammas should occur. Figure 4 shows the same data for locations *III* and *IV* separated by 725 miles. It is apparent that the range of the

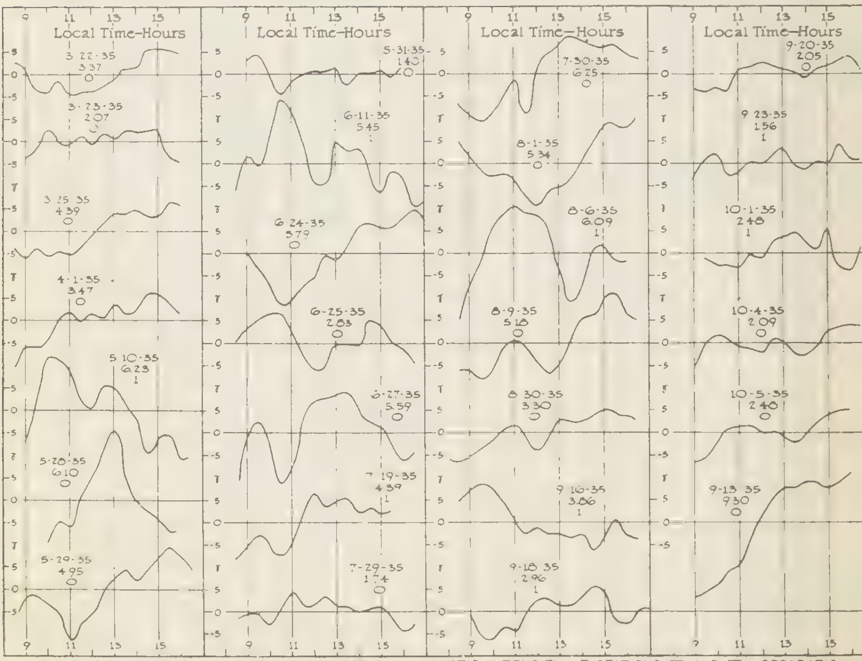

FIG. 4—DIFFERENCES IN VARIATIONS OF VERTICAL MAGNETIC INTENSITY AT STATIONS III AND IV—SEPARATION 725 MILES

difference-curve is often half the range of the diurnal variation itself and that difference-curves of large amplitude are not confined to disturbed days.

In addition to purely local fluctuations which form, as will be shown later, the major contribution to the ordinates of the difference-curves of Figures 3 and 4, one would expect that the diurnal curves would differ in shape due to the difference in geographical position of the points of observation, especially with regard to latitude. It is also not altogether inconceivable that certain local differences of the electrical conductivity of the Earth's crust might slightly, but consistently, affect the shape of diurnal-variation curves, so as to give the residual curves of Figures 3 and 4 a systematic character. To ascertain the existence of such an effect

the average difference-curve was computed for 11 sets of two geographic locations as in Figure 5. Under the Roman numerals the longitude-separations of the locations are given. A relationship seems to exist between the shape of the average difference-curves and the longitude-separation $\Delta\lambda$ of the locations—the longitude-separation is always opposite in sign to the slope of the difference-curves between 9^h and 13^h. Roughly estimating the value of this slope and then plotting it against the corresponding longitude-difference a series of points is obtained which lie in a restricted portion of only one quadrant, as shown in Figure 6. In view of the location of the stations it does not seem possible to explain this behavior by the relative distribution of land and sea, an argument advanced for the failure of harmonic analyses to fit the average vertical-intensity curves of even a few observatories by better than about 40 per cent[1].

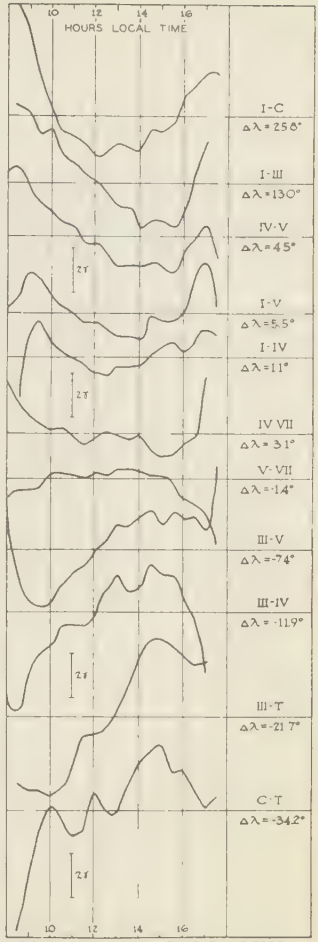

FIG 5—AVERAGE HALF-HOURLY DIFFERENCES OF VARIATIONS IN VERTICAL MAGNETIC INTENSITY

The manner in which the magnitude of the deviations illustrated by Figures 3 and 4 increases with increasing geographical separation furnishes an indication of the average range of local fluctuations. To obtain a quantitative estimate of this range, the sum of the absolute values of the half-hourly ordinates was taken over all days, divided by their total number, and multiplied by 0.845. The probable difference thus obtained was plotted for each available set of two geographic points against their separation in miles in Figure 7. This Figure is based on half-hourly comparisons of 510 pairs of diurnal-variation curves. Local fluctuations appear to be nearly independent at points 800 miles apart.

It is necessary to inquire whether the systematic character of the average difference-curves shown in Figure 5 contributes materially to the ordinates of the probable difference-curve of Figure 7. Let the half-hourly ordinates of the difference-curves of Figure 3, for example, be arranged in the array

[1]J. Bartels, Wien-Harms Handbuch experimental Physik, **25**, part 1, p. 649 (**1928**).

$$
\begin{array}{l}
a_{11}\ a_{12}\ a_{13}\ \ldots\ a_{1i}\ \ldots\ a_{1j} \\
\quad a_{22}\ \ldots\ldots\ a_{2i} \\
\\
a_{n1}\ \ldots\ldots\ldots\ a_{ni}\ \ldots\ a_{nj} \\
\\
a_{m1}\ a_{m2}\ \ldots\ldots\ a_{mi}\ \ldots\ a_{mj}
\end{array}
$$

the first subscript referring to the day and the second to the time of day. Neither the rows nor the columns of this array necessarily contain the same number of values of a. If there are N_i values of a in the i th column then the average ordinate for this half-hour is $(1/N_i)\sum_{1}^{m} a_{ni} = A_i$. To find out whether A_i forms a substantial part of the values of a_{ni} we could subtract it from every a_{ni} and see how much smaller the sum of the absolute values of resulting differences $\sum_{1}^{m}\sum_{1}^{j}|a_{ni} - A_i|$ is than $\sum_{1}^{m}\sum_{1}^{j}|a_{ni}|$.

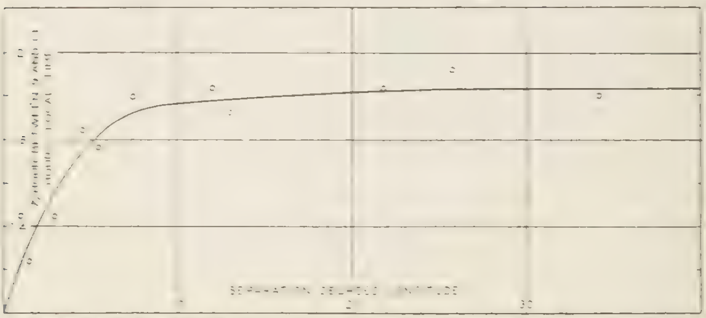

FIG. 6—SLOPE OF AVERAGE CURVE FROM 9 TO 3 HOURS LOCAL TIME AND LONGITUDE SEPARATION OF STATIONS

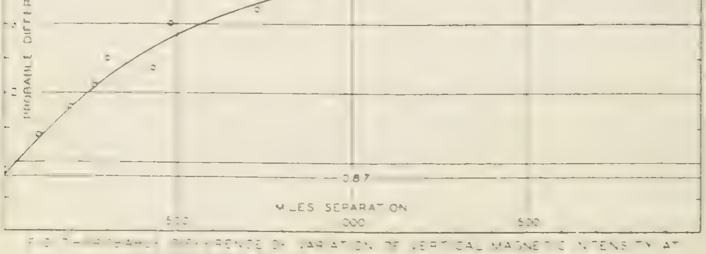

FIG. 7—PROBABLE DIFFERENCE OF VARIATION OF VERTICAL MAGNETIC INTENSITY AT TWO LOCATIONS AS A FUNCTION OF SEPARATION OF STATIONS

This calculation is, however, quite laborious and it is more expedient to effect the separation of the contribution of systematic variations in another way. It can be shown that $(1/N)\sum_1^m{}^n \sum_1^j [a_{nt}-A_t]^2=(1/N)\left(\sum_1^m{}^n \sum_1^j a_{nt}^2-\sum_1^j A_t^2\, N_t\right)$ where N is the total number of half-hourly differences. The first term of the right-hand side of this equation represents the mean-square ordinate of the difference-curves, while the second is the mean-square ordinate of the average curve. Thus the difference of the two expresses the contribution of random fluctuations alone to the mean-square ordinate of the difference-curve. Table 1 shows the results so calculated for nine sets of two geographic points. As expected, the contribution of systematic differences is seen to be small, demonstrating that the major part of local fluctuations is of random character.

It is of interest to obtain a measure of the relative magnitude of the local fluctuations with respect to the total amount of variation suffered by the vertical magnetic intensity from about 8^h to 17^h, local time. The latter may be estimated by computing the half-hourly departures of the original diurnal-variation curves from the daily mean and then taking the mean of their absolute values for a representative number of days. Multiplying this mean by 0.845, gives the probable difference that would exist in the vertical magnetic intensity at two places, if the variations were entirely independent. This calculation was made for three sets of

TABLE 1—*Contribution of systematic variations to mean-square differences*

Set	(I-III)	(I-IV)	(I-V)	(III-IV)	(III-V)	(IV-V)	(IV-VII)	(V-VII)	(I-C)
$1/N)\sum_1^m \sum_1^j (a_{nt})^2$	26.2	14.7	13.7	25.2	20.7	10.6	7.3	5.1	32.8
$1/N)\sum_1^m \sum_1^j (a_{nt}-A_t)^2$	23.7	14.3	12.9	22.4	18.5	8.7	6.8	4.9	29.3
$1/N)\sum_1^j (A_t)^2 N_t$	2.5	0.4	0.8	2.8	2.2	1.9	0.5	0.2	3.5

25 diurnal curves evenly distributed throughout the period, all stations contributing data in approximately equal amounts. The mean probable ordinate 5.9 gammas thus obtained is represented on Figure 7 as a horizontal line. Allowing for instrumental errors, the probable difference in gammas, on the basis that the variations are independent, would be $\sqrt{(5.9)^2-(0.8)^2}=5.85$. Actually there is, of course, some correlation, so that the probable difference in gammas in the variations at points 800 miles apart, for instance, has the smaller value of $3.38=\sqrt{(3.4)^2-(0.8)^2}$. It may be concluded, therefore, that for this separation 58 per cent of the magnetic variations behave independently.

The quantitative results of this investigation are summarized in Figure 7 and are important insofar as they give us an estimate of the average magnitude and range of local disturbances. They have been

obtained, however, by statistical methods and it is only reasonable to suppose that some valuable information contained in the original data has been discarded. In order to get some picture of what actually happens, it is necessary to consider how on one particular day the diurnal variation changes from one location to another. Obviously the data presented here are poorly suited for such studies. Yet it is possible to gather a few facts from the selected groups of diurnal curves drawn in Figure 8.

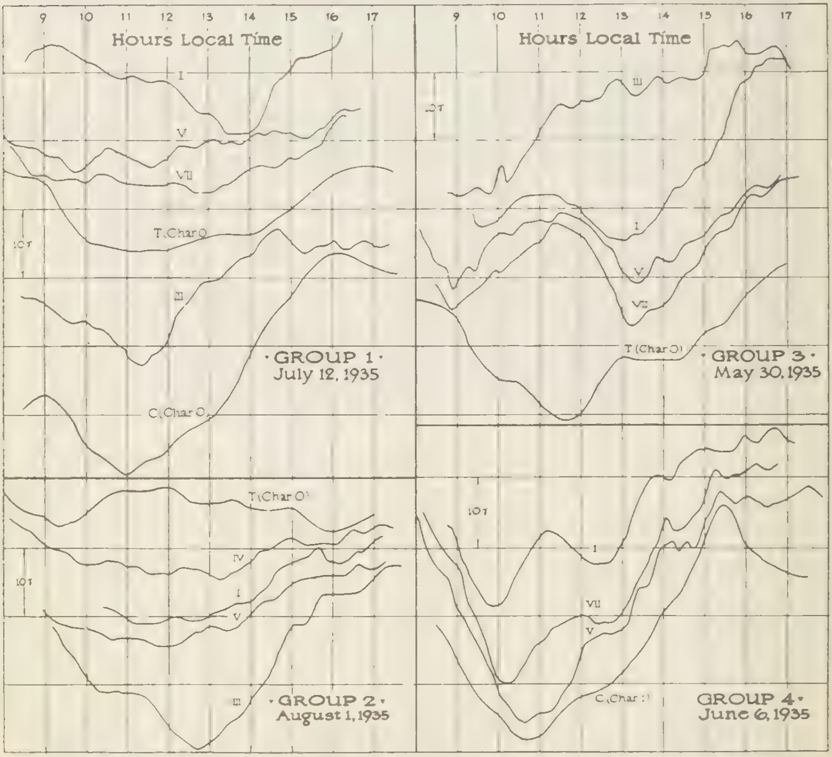

FIG 8—VARIATIONS OF VERTICAL MAGNETIC INTENSITY AT VARIOUS STATIONS

Perhaps the most striking example showing how large residuals are obtained when two diurnal curves are subtracted is afforded by Group 1. The curves designated by Roman numerals refer to the locations of Figure 2 and were plotted from 10-minute readings, while the Cheltenham (C) and Tucson (T) curves were plotted from instantaneous values every half-hour. Thus in eastern Colorado (I) the minimum occurred at $13^h\,40^m$ while in southern Mississippi (III), it happened at $11^h\,20^m$ In southern and central Oklahoma (V and VII) no pronounced minimum appeared At Cheltenham the minimum occurred even a little earlier

than in Mississippi while at Tucson both minima are in evidence. Groups 2 and 3 likewise show similar departures in amplitude and phase.

Group 4 exhibits a gradual disappearance of the sharp maximum at $11^h\ 10^m$ and of the minimum at $12^h\ 30^m$ as we travel southeast from Station *I* to Station *V*. Moreover a difference of 10 gammas is accumulated from $11^h\ 20^m$ to $12^h\ 30^m$ between stations *V* and *VII* which are only 100 miles apart.

It should be emphasized that the presence and the magnitude of local magnetic variations are independent of magnetic activity as expressed by international character-numbers. It would be only natural to expect that the mean of the absolute values of the half-hourly ordinates of each difference-curve (hereafter called "mean departure"), would be greater on disturbed days than on quiet ones. Instead of investigating each set of two geographic points separately, they were all made comparable by multiplying the mean departures of each set except (*C-T*) by a suitable factor greater than unity. The multiplying factors were obtained from the curve of Figure 7. Thus reduced, the mean departures of all sets were made to oscillate about the average value of 4.9 gammas. The reduced mean departures which occurred on days of international character 0.0 and 0.1 were averaged, the ones occurring on days characterized by the numbers 0.2 and 0.3 were likewise averaged, and so on. These averages are plotted on Figure 9 against

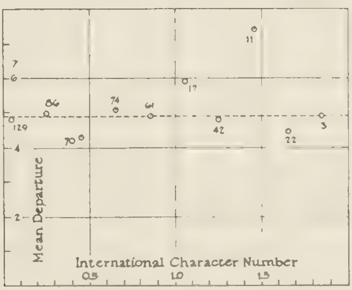

FIG. 9—INDEPENDENCE OF LOCAL VARIATIONS IN VERTICAL MAGNETIC INTENSITY AND MAGNETIC ACTIVITY

the corresponding international character-numbers and show definitely that the local irregularities are independent of magnetic activity. The number affixed to each point indicates the number of individual comparisons of two curves, so that the points should be weighted according to these numbers. Thus the last three points represent only nine per cent of the data. It is significant that the 129 comparisons made on 0.0 and 0.1 days yielded an average mean departure of 4.8 gammas an insignificant deviation of 0.1 gamma from the over-all average. The examination of 15 sets of curves for 0.0 and 0.1 days, revealed the presence of local differences in phase and amplitude of the same character as shown by the illustrations of Figure 8.

The simultaneous features exhibited by the group of curves in Figure 10, which are plotted against 90° west meridian time, seem to indi-

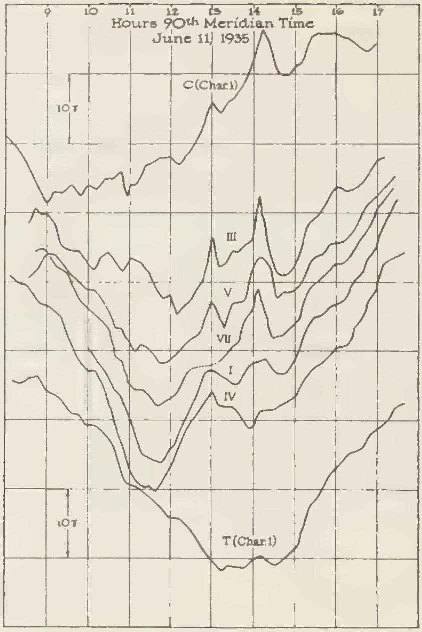

FIG 10—SIMULTANEOUS VARIATIONS IN VERTICAL MAGNETIC INTENSITY

cate that even in the case of simultaneous disturbance the expression of the disturbance is greatly dependent upon local factors.

The existence of diurnal-variation distributions depicted in Figure 8 can be easily accounted for on the basis of the atmospheric dynamo-theory of magnetic variations. According to this view the geographic uniformity of the variation is predicated on the uniformity of circulating air-currents in the upper atmosphere immediately overhead, which are supposedly brought about by the diurnal rotation of the Earth, the thermal expansion of the atmosphere, the gravitational solar tide, and resonance-phenomena of the atmosphere. Hulburt[2] has directed attention to the fact that winds of considerable velocities are not uncommon at the height of the ionosphere. The regular convection-currents to which the diurnal magnetic-variation is ascribed are thus apt to be disturbed by local air-currents in such a way as to give the magnetic variation at points distant by five or six times the ionospheric height a totally different character. By simultaneous observation of local magnetic fluctuations at a sufficiently large number of points, it would be possible to delineate the paths of local winds in the upper atmosphere which may perhaps act as a trigger for certain meteorological phenomena. Indeed, the absence of correlation between magnetic and meteorological phenomena can hardly be regarded as proven until areal surveys of magnetic fluctuations are available; for even if the absolute values or the time-rates

[2]Pub. Nat. Res. Council, Trans. Amer. Geophys. Union, 13th annual meeting, 124 (1932).

of change of the magnetic elements may bear no apparent relationship to the weather, the behavior of the space-gradients of these time-rates is not known in detail. This possible connection between magnetic and meteorological phenomena is not viewed with favor but it deserves close scrutiny because it has a remote chance of bringing results of practical value.

On the basis of the drift-current and diamagnetic theories of magnetic variations the distributions shown on Figure 8 find no reasonable explanation. The very fact that they can exist at all indubitably indicates that these hypotheses are at variance with what actually takes place. In order to reproduce the observed differences in the character of the magnetic variations as shown on Figure 8, the rate of ionization would have to vary locally in magnitude and in phase by amounts entirely out of line with what one would expect from radio data at times of solar eclipses.

A necessary condition for a good representation of a geophysical element which suffers spatial variations from a restricted source is an areal survey in which the spacing of control-points is of the same order of magnitude as the shortest distance from the observer to the region where the disturbances originate. It has been demonstrated that the major part of the short-time magnetic fluctuations, in the vertical component at least, are of local origin and therefore it may be concluded that none of the measurements of magnetic variations carried out so far have given an adequate representation of the phenomenon. Thus the poor spacial distribution of the data made possible the inception of the diamagnetic and drift-current theories of magnetic variations.

It should be remembered that while the data presented above are extremely fragmentary, the fact that they are adequate to establish significant conclusions indicates that further study of local magnetic variations is almost certain to enrich our knowledge of terrestrial magnetism. If, for example, air-temperature measurements were taken only at magnetic observatories and if one should have attempted to discover the agents responsible for the variations from the analysis of diurnal-inequality curves obtained from hourly means of five selected days per month, it would be surprising indeed if all the factors which are known to cause changes in air-temperature would have been apprehended. Such a study, however, would have revealed a diurnal periodicity not unlike that of the magnetic elements and, in addition, the range would have been found to be greater for stations on land than for stations at sea. Seasonal variations in the amplitude of the diurnal change would also have been discovered. These results would be true to fact but they would be grossly inadequate as a basis for a theory of atmospheric circulation. To get an idea of how the atmosphere behaves, average curves from five selected days per month would obviously be of insignificant worth, compared with the knowledge derived from the consideration of simultaneous sets of values of the meteorological elements at a sufficient number of points distributed over a substantial portion of the Earth's surface. It is the study of the departures from average conditions and the areal distribution of these departures, which not only enables the meteorologist to describe a particular set of events but also brings him a general understanding of atmospheric phenomena. Qualitatively, at least,

the quiet-day variation of a magnetic element possesses the properties enumerated in the discussion of our hypothetical investigation of air-temperature. Perhaps the most significant differences in the behavior of the two phenomena are that the mean value of a magnetic element is not subject to pronounced seasonal fluctuations and that meteorological storms never embrace the Earth as a whole as do magnetic storms. These differences are, of course, fundamental, but it is nevertheless patent that a study of local irregularities of the variations of the magnetic elements may easily be as important for the formulation of a satisfactory theory of diurnal variations as the search for periodicities.

A thorough study of local magnetic variations calls for the development of cheap and compact recording-equipment which could operate for long periods of time without requiring attention; but before such an expensive program is undertaken it may be possible to gather some information from day-to-day comparisons between European observatories, some of which fortunately are situated close enough together for this purpose.

In closing I wish to mention that the preparation of this paper was made possible by Dr. E. A. Eckhardt who generously provided help for the compilation of the data. Considerable material was gathered in the course of discussions with Dr. M. Muskat of the Gulf Research and Development Company, and with A. G. McNish of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington. Credit is also due to Messrs W. J. Spangler and J. K. Munhall who did most of the computational work.

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ON THE THEORY OF THE UNIFILAR VARIOMETER[1]

By H. H. Howe

Abstract—Vectors are used in this treatment. Neglecting inhomogeneity of the field of control-magnets, the simple, inclusive equation is obtained: Scale-value per radian for changes normal to the magnetic axis $=(k+P)$, where k is ratio of torsion-constant to magnetic moment and P is field parallel to axis. Some consequences are discussed, showing superiority over other scale-value equations. This equation is adequate for the scale-value of an H-variometer unless the readings are to be combined accurately with those of another variometer.

The subject is approached from a more general point of view. Horizontal intensity (H) is experimentally a function of ordinate (n), declination (D), and temperature (t). It is expressed by a Taylor's series in those variables. The resulting analysis shows: (a) This method avoids mistakes frequently made when second-order effects are considered; (b) when properly defined in the most convenient way, the temperature-coefficient is independent of ordinate and declination; (c) considerable error has resulted from the use of the wrong sign for the temperature-coefficient of rigidity of quartz.

Consideration of variations of scale-value shows: (a) Turning the torsion-head affects the base-line scale-value very little; (b) a simple formula for the effect of change of optical lever with ordinate results; (c) the principal part of the variation with ordinate is due to the fact that when the magnet turns, part of the Earth's field acts parallel to its axis; (d) for a simple H-variometer the temperature-coefficients of base-line value and base-line scale-value are precisely the same; (e) a sensitivity-control magnet may cause a large temperature-effect on scale-value; (f) optical compensation produces an effect opposite in sign to the normal one, sometimes smaller, sometimes much larger; (g) the correction necessary to observed scale-values is deduced. The effects of change of D are considered. These may be considerable even with a properly-adjusted variometer, especially if it be uncompensated or have optical compensation.

A similar treatment for a D-variometer shows: (a) The scale-value may have considerable error unless corrected for the field of other magnets; (b) the effect of change of H is small and is wholly negligible if the variometer is properly adjusted—hence a D-variometer is more accurate than any intensity-variometer; (c) error in orientation may be detected and its magnitude may be estimated from the variometer's temperature-coefficient.

Similar methods applied to the component in a fixed direction show that the formulas are somewhat simpler than for an H-variometer. Maladjustments are discussed and it is shown that the formulas used for computing diurnal variations of X and Y from those of H and D are frequently incorrect. Certain possible improvements in instrument-design and operation are suggested.

1. *Description*—A unifilar variometer has a horizontal recording magnet free to turn about a vertical axis, suspended by a fiber (usually quartz). A mirror attached to the magnet reflects light from a point-source to a sheet of photographic paper, the magnetogram (or "gram"), on a drum driven by clockwork. A fixed mirror gives a straight base-line. The distance from base-line to curve is the ordinate. Sometimes control-magnets are placed nearby to reduce temperature-effects or to change sensitivity. Some variometers have optical compensation, a mirror supported on a bimetallic strip just in front of the one attached to the magnet, so that change of temperature deflects the light-spot if the magnet does not move.

2. *Types of unifilar variometers*—Unifilar variometers may be divided

[1]Publication authorized by the Director, United States Coast and Geodetic Survey.

into three types, accordingly as they are intended to measure change of (*a*) the component of the Earth's field in a fixed direction [as true north (X-variometer) or true east (Y-variometer)], (*b*) the horizontal component of the Earth's field (H-variometer), (*c*) the declination, or angle between horizontal component and true north (D-variometer). The H-variometer is sometimes thought of as belonging to type *a* rather than *b*. In the following discussion sections 3, 4, and 5 apply to any type; sections 6 to 18 deal principally with type *b*, some parts applying to any type; sections 19 to 23 deal with type *c*, and section 24 deals with type *a*. Magnetic intensities are expressed in γ, 100,000 γ being one oersted, the CGS electromagnetic unit.

3. *Notation*—Vectors are denoted by bold-face type. The "scalar product" of two vectors is the magnitude of one multiplied by the projection of the other upon it, expressed by a dot between them. It is distributive with respect to addition, whence its derivative is found as for ordinary products.

F is the magnetic field of the Earth, **H** its horizontal component, **X** its north component, and **Y** its east component. **C** is the average at the two poles of the recording magnet of the sum of all other fields. Effects due to non-uniformity of **C** are not treated here, although they are mentioned in places. M is the magnetic moment of the recording magnet; M may also refer to the magnet itself. **p** is a unit-vector parallel to the magnetic axis of M, directed from south pole to north pole. $P = (\mathbf{F}+\mathbf{C})\cdot\mathbf{p}$ is the magnitude of the field parallel to the magnetic axis. h is the torsion-constant of the fiber. $k = h/M$ is a function of temperature only. It does not depend upon the position of M or upon **F** (neglecting induction). It changes slowly with time. ψ is the amount of torsion in the fiber. **n** is a unit horizontal vector normal to **p**. Rotation of **p** toward **n** increases ψ. n is the ordinate on the magnetogram in mm. t is the temperature in degrees Centigrade. All angles are measured in radians unless otherwise stated.

4. *Equilibrium*—Three torques about a vertical axis act on M: $M\mathbf{F}\cdot\mathbf{n}$ and $M\mathbf{C}\cdot\mathbf{n}$ tend to increase ψ, and $h\psi$ tends to decrease ψ. Equating and dividing by M

$$\mathbf{F}\cdot\mathbf{n} + \mathbf{C}\cdot\mathbf{n} = k\psi \qquad (1)$$

5. *Scale-value*—If **F** changes infinitesimally, ψ changes. This changes **n**. Since we neglect change of **C**, which could arise only from its inhomogeneity

$$\mathbf{n}\cdot d\mathbf{F} + \mathbf{F}\cdot d\mathbf{n} + \mathbf{C}\cdot d\mathbf{n} = k\, d\psi \qquad (2)$$

Since **n** is of unit-length, the infinitesimal d**n** is normal to it. From Figure 1, d**n** is of length dψ and parallel to the unit-vector $-\mathbf{p}$. Therefore $d\mathbf{n} = -\mathbf{p}\; d\psi$, and

$$\mathbf{n}\cdot d\mathbf{F}/d\psi = k + (\mathbf{F}+\mathbf{C})\cdot\mathbf{p} = (k+P) \qquad (3)$$

This is the fundamental scale-value equation. k is an equivalent magnetic field,[2] expressible in gammas. The scale-value per radian with respect to changes normal to the axis (a constantly changing direction) is $(k+P)$. k is independent of position, while P varies as M turns.

[2]This point of view was suggested by Ad. Schmidt in Ergebnisse der magnetischen Beobachtungen in Potsdam und Seddin im Jahre 1908 (hereafter referred to as *EMB*), p. 39, line 7.

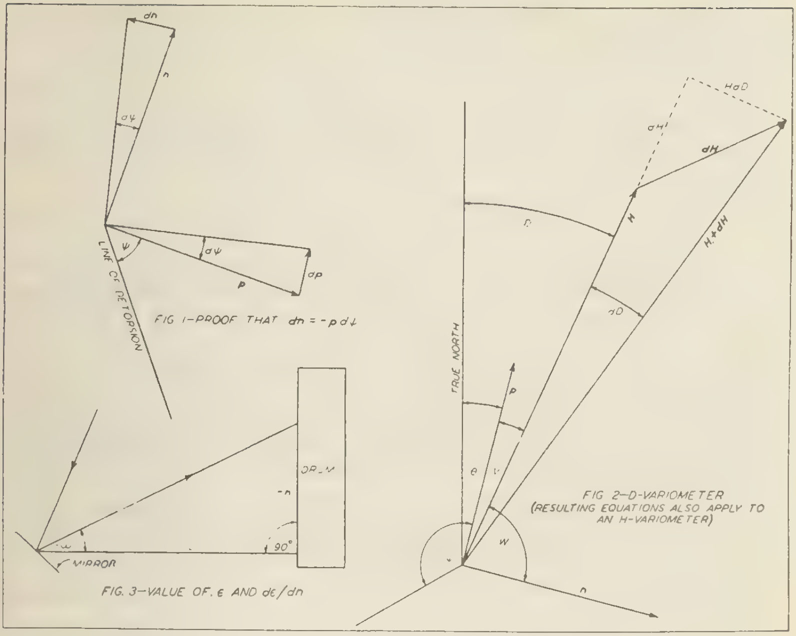

FIG 1—PROOF THAT dn = -p dψ

FIG 2—D-VARIOMETER (RESULTING EQUATIONS ALSO APPLY TO AN H-VARIOMETER)

FIG. 3—VALUE OF ε AND dε/dn

6. *H- and D-variometers*—Let D be the declination and θ the angle between **p** and true north, reckoned positive clockwise from true north. Take the sign of ψ so that, for change of θ, $\mathrm{d}\theta = +\mathrm{d}\psi$. For an H-variometer we consider specifically only the case of north end west; some signs must be changed for north end east. Write

$$\theta - D + 90° = w \text{ and } D - \theta = v = 90° - w \tag{4}$$

By Figure 2, for infinitesimal d**F**

$$\mathbf{n}\cdot\mathrm{d}\mathbf{F} = (\cos w)\,\mathrm{d}H + H\,(\sin w)\,\mathrm{d}D \tag{5}$$

whence, by (3)

$$(\cos w)\,\mathrm{d}H + H\,(\sin w)\,\mathrm{d}D = (k+P)\,\mathrm{d}\theta \tag{6}$$

Two conclusions may be drawn for the H-variometer. First, the D-terms are to be neglected, causing an error in $\mathrm{d}H$. Second, this is permissible only if $H\,(\sin w)\,\mathrm{d}D$ is negligible compared with $(\cos w)\,\mathrm{d}H$. Since $\mathrm{d}H$ and $H\mathrm{d}D$ are of the same order of magnitude, $\sin w$ is negligible compared with unity. Then surely $\cos w$ can be replaced by unity, and

$$\mathrm{d}H/\mathrm{d}\theta = (k+P) \tag{7}$$

a scale-value formula (in γ/radian) sufficient for most purposes. If more accurate results are desired, we must take account of $\triangle D$.

Similarly, for a D-variometer $\cos w$ must be negligible and $\mathrm{d}D/\mathrm{d}\theta = (k+P)/H$.

In effect, **F** is resolved along **n** and **p** while d**F** is resolved along **H** and perpendicular to it. The advantage of vectors is that we can differentiate first and then resolve each in the more convenient way.

Some day it may be desired to compute two components by combining accurately the readings of two variometers. Methods of doing so are indicated later (see section 10 and following). Even now it may be necessary to use two variometers if there be maladjustment (section 25).

The value of P, needed later, is

$$P = H\sin w + \mathbf{C}\cdot\mathbf{p} \tag{8}$$

7. *Methods*—We could solve (1) for k and substitute into (6), using (8) and omitting the term in dD

$$\mathrm{d}H/\mathrm{d}\theta = H\,(\tan w + 1/\psi) + (\mathbf{C}\cdot\mathbf{n}/\psi + \mathbf{C}\cdot\mathbf{p})\sec w \tag{9}$$

This formula agrees with that given by D. L. Hazard[3] for the case $\mathbf{C}=\mathbf{0}$, and with that given by G. Hartnell for a particular arrangement of control-magnet[4], except that their formulas neglect the fact that dH/dθ involves D through w.

(9) is useful to get dH/dθ approximately as a rough check on theory, since ψ, **C**, and H are known more accurately than is k without special observations. However, k is independent of θ while ψ is not, so that (7) is better for most purposes. It is easier to remember, its meaning is more readily visualized, and it is easier to use correctly in determining variations of scale-value.

8. *Constant part of dH/dθ*—Under standard conditions, if one condition is $w=0$, dH/d$\theta = k_0 + \mathbf{C}_o\cdot\mathbf{p}_o$. If the variometer is not properly oriented, $w\neq 0$. $\mathbf{C}_o\cdot\mathbf{p}_o$ is chiefly due to sensitivity-control magnets[5]. The part due to other variometers is negligible compared with the uncertainty of k.

9. *Variation of dH/dθ*—From (7), (4), and (8) it follows: (*a*) When the magnet turns through the small angle ϕ, w increases by ϕ, and P and dH/dθ increase by $H\phi$ (see section 15); (*b*) when D increases by ϕ, w decreases by ϕ, and P and dH/dθ decrease by $H\phi$ (see section 18); (*c*) when temperature increases, k increases and **C** decreases (see section 16).

To determine accurately the results of these variations, closer analysis is needed. The method used also investigates other features, including effects of change in t and D.

10. *General theory*[6]—The physically independent variables (that is, changes from natural causes ignoring changes not amenable to mathematical treatment such as slipping of the fiber and slow changes with time) are H, D, and t. n is a function of them. Experimentally, we measure n, D, and t (D is "measured" by another variometer, to an accuracy sufficient for the purpose, or successive approximations may be used) and determine H as a function of them, H (n, D, t). These

[3]Directions for magnetic measurements, 2d Edition, U. S. Coast Geod. Surv., Ser. 166 (1921) (hereafter referred to as *DMM*), p. 101.

[4]Horizontal-intensity variometers, U. S. Coast Geod. Surv., Spec. Pub. No. 89 (1922) (hereafter referred to as *HIV*), formula (84).

[5]Given in *HIV*, equation (89).

[6]The basis of the following point of view was proposed by L. Olshevsky, formerly of the U. S. Coast and Geodetic Survey.

three are "independent" variables, and in partial differentiation two are constant.

The change in H between observed conditions and standard conditions is

$$\triangle H = H(n_1, D_1, t_1) - H(0, D_0, t_0) = H(n_1, D_1, t_1) - H(n_1, D_0, t_1) + H(n_1, D_0, t_1) - H(0, D_0, t_1) + H(0, D_0, t_1) - H(0, D_0, t_0) \quad (10)$$

$$\triangle H = \int_0^{n_1} \frac{\partial H}{\partial n}(n, D_0, t_1)\,\mathrm{d}n + \int_{D_0}^{D_1} \frac{\partial H}{\partial D}(n_1, D, t_1)\,\mathrm{d}D + \int_{t_0}^{t_1} \frac{\partial H}{\partial t}(0, D_0, t)\,\mathrm{d}t \quad (11)$$

The integrands are to be called, respectively, the scale-value (s), the spurious factor, and the temperature-coefficient (Q). We write $s(0, D_0, t_0) = s_0$, etc.

Given n, D, and t, the definition of Q is: Reduce D to D_0; change H so that n becomes 0; change t by the infinitesimal $\mathrm{d}t$; change H by $\mathrm{d}H$ to return n to 0. Then $\mathrm{d}H/\mathrm{d}t = Q$. Thus, contrary to what has been stated,[7] Q depends on temperature only. We could rearrange subscripts in (11) and make Q dependent on n and s independent of t, but since t changes more slowly than n, that would be inconvenient. Had we said merely $Q = \partial H/\partial t$ (essentially the usual definition), it would vary with n and D. But we here define Q exactly. Since it is *possible* to make it independent of n and D, the logical method is to do so.

Equation (11) can be made clearer although less complete by using Taylor's series, retaining first- and second-order terms

$$\triangle H = (A + En/2 + J\triangle t)n + (B + F\triangle D/2 + In + K\triangle t)\triangle D + (C + G\triangle t/2)\triangle t \quad (12)$$

where A, B, and C are the first partial derivatives of H; and E, F, G, I, J, and K are the second derivatives.

One should consider how many terms of (12) should be used. It is customary to consider the terms in A and C, and sometimes in B and E. The others are probably usually neglected. However, the values of all the coefficients should be found for the particular variometer and it should be determined which terms are relevant for the ranges likely to occur. In particular, the terms in F and I may be larger than that in E.

If second-order terms are dropped, use any convenient constant values of n, D, and t in the first derivatives. Otherwise use 0, D_0, t_0 in the first derivatives and any convenient constant values in the second derivatives (if this involves appreciable uncertainty in the result, third derivatives should be used).

In (12) it is obvious that Q is independent of n and D, since $Q = C + G\triangle t/2$. Second-order terms are strictly valid only for instantaneous values, not for hourly means[8].

11. *Derivatives of H*—Express the complete differential of (1) in terms of the differentials of the independent variables n, D, and t, and of the dependent variable H. C and k are functions of t alone. For θ there are two cases: (a) With optical compensation, n is determined physi-

[7] *EMB*, p. 39, line 30.

[8] Noted by Ad. Schmidt, *EBM*, p. 38, line 7 from bottom, for the term $In\,\Delta D$.

cally by θ and t and therefore experimentally θ is a function of n and t; (b) with no optical compensation, θ is experimentally a function of n alone, this being the special case $\partial\theta/\partial t=0$. Let

$$\partial\theta/\partial n=\epsilon,\ \partial\theta/\partial t=\eta,\text{ and } \mathrm{d}k/\mathrm{d}t=qk \tag{13}$$

whence $\mathrm{d}\theta=\epsilon\mathrm{d}n+\eta\,\mathrm{d}t$.

Add to the right side of (3) the terms of the differential of (1) involving dt, namely $-\mathbf{n}\cdot\mathrm{d}\mathbf{C}+\psi\mathrm{d}k$. Substituting for ψ from (1)

$$\mathbf{n}\cdot\mathrm{d}\mathbf{F}=(k+P)\ (\epsilon\mathrm{d}n+\eta\mathrm{d}t)-\mathbf{n}\cdot\mathrm{d}\mathbf{C}+q\ (H\cos w+\mathbf{C}\cdot\mathbf{n})\ \mathrm{d}t \tag{14}$$

This equation holds for any unifilar variometer. For an H-variometer, by (5) and (8)

$$\begin{aligned}\mathrm{d}H=&[H\tan w+(k+\mathbf{C}\cdot\mathbf{p})\sec w]\epsilon\ \mathrm{d}n-H\ (\tan w)\ \mathrm{d}D\\&+[qH+(q\mathbf{C}\cdot\mathbf{n}-\mathbf{n}\cdot\mathrm{d}\mathbf{C}/\mathrm{d}t)\sec w+(k+P)\eta\sec w]\ \mathrm{d}t\end{aligned} \tag{15}$$

The partial derivatives of H are identified by comparison of (15) with

$$\mathrm{d}H=A\ \mathrm{d}n+B\ \mathrm{d}D+C\ \mathrm{d}t \tag{16}$$

It is most efficient to compute the second derivatives of H at once. The method is explained for one and results are given for all. $I=\partial^2H/\partial n\partial D=\partial A/\partial D=\partial B/\partial n$. It is vital to remember that in getting $\partial B/\partial n$, D and t are constant. Hence, when n changes, H must change and, by definition, $\partial H/\partial n=A$[9]. By (4) and (13), $\partial w/\partial n=\epsilon$, $\partial w/\partial t=\eta$, $\partial w/\partial D=-1$. Therefore

$$I=\partial B/\partial n=\partial(-H\tan w)/\partial n=-A\ \tan w-H\epsilon\sec^2 w \tag{17}$$

As a check, compute $\partial A/\partial D$, noting that $\partial H/\partial D=B$, and that k, $\mathbf{C}$, $\mathbf{p}$, and ϵ are independent of D

$$\partial A/\partial D=[B\ \tan w-H\sec^2 w-(k+\mathbf{C}\cdot\mathbf{p})\sec w\tan w]\epsilon \tag{18}$$

On substituting the values of A and B, these equations agree.

Similarly (remembering that $\mathbf{n}$ and $\mathbf{p}$ are functions of θ, and that, for example, $\partial\mathbf{p}/\partial n=\epsilon\mathbf{n}$), making some simple substitutions

$$E=\partial^2H/\partial n^2=\partial A/\partial n=2A\epsilon\tan w+\epsilon^2H+\mathbf{C}\cdot\mathbf{n}\epsilon^2\sec w+(A/\epsilon)\ (\mathrm{d}\epsilon/dn) \tag{19}$$

$$F=\partial^2H/\partial D^2=\partial B/\partial D=-B\ \tan w+H\sec^2 w=H\ (1+2\tan^2 w) \tag{20}$$

$G=\partial^2H/\partial t^2$ has no theoretical expression, except in terms of the variation of temperature-coefficients with temperature, which is usually unknown.

$$\begin{aligned}J=\partial^2H/\partial n\partial t=\partial C/\partial n=\partial A/\partial t=&\epsilon[qk\sec w+C\tan w+(\mathrm{d}\mathbf{C}/\mathrm{d}t\cdot)\mathbf{p}\sec w]\\&+\eta(A\ \tan w+\epsilon H+\mathbf{C}\cdot\mathbf{n}\epsilon\sec w)\end{aligned} \tag{21}$$

[9]Many errors have been made by disregarding these principles. For example, (9) can be used to obtain correctly the variation of scale-value with θ if it be remembered that H is a variable whose derivative is (9). Attention to details is not necessary so long as only first-order terms are considered, but when second-order terms are considered, the experiences of a number of investigators show that incorrect results are perhaps more likely than correct ones. No doubt correct results are possible without the point of view given here, but with this point of view they come almost automatically.

$$K = \partial^2 H/\partial D\partial t = \partial C/\partial D = \partial B/\partial t = -C \tan w - H\eta \sec^2 w \tag{22}$$

In the above we have used $\partial\epsilon/\partial t \equiv \partial\eta/\partial n = 0$ (see section 14).

12. *Temperature-coefficient*—By (11) and (16), the temperature-coefficient Q is $C(0, D_0, t)$. Since dQ/dt is usually unknown, a constant value of Q is used. (The same is true of q and dk/dt, although it is impossible for all to be constant.) Use, therefore, $Q = C(0, D_0, t_0)$. Variation-rooms are usually insulated and errors from using constant Q (as well as those due to its uncertainty) are negligible over short periods, while over long periods they appear as base-line drift. dQ/dt may perhaps be detected in comparison of two variometers, as was recently done by the author in the case of two Z-variometers at Cheltenham.

Case I: Simple variometer ($\eta = 0$; $\mathbf{C} = \mathbf{0}$)—By (15) and (16),

$$Q = qH \tag{23}$$

The relation of dk/dt to dM/dt is discussed by Hartnell[10]. Hartnell's temperature-coefficient of rigidity (μ) for quartz was taken from the Smithsonian Physical Tables, and the author has discovered that it is there given with the wrong sign, since $d\mu/dt = +0.00012\mu$[11]. Taking account of thermal expansion, $dh/dt = 0.00016h$. If $q_1 M = -dM/dt$, $q = q_1 + 0.00016$. q_1 is positive, usually between 0.0003 and 0.0006.

Case II: No optical compensation ($\eta = 0$)—By (15), temperature-compensation depends upon $\mathbf{C}_\circ \cdot \mathbf{n}_\circ$ and its derivative, but not upon the type of apparatus. The formulas for $Q = 0$ agree approximately with those of Schmidt[12] and Hartnell[13] for the types of apparatus they describe.

Two differences from Hartnell's formulas are that he neglects temperature-effects on the fiber and on the distance between magnets, remarking that a slight change of this distance cares for them. The former of these is discussed above. The coefficient of expansion of brass is about 0.000019, whence $d\mathbf{C}/dt = -(q_2 + 0.00006)\mathbf{C}$, if q_2 is the temperature-coefficient of the compensating magnet. Hence

$$Q_0 \doteq \mathbf{C}_\circ \cdot \mathbf{n}_\circ \, (q_1 + q_2 + 0.00022) \sec w + H\,(q_1 + 0.00016) \tag{24}$$

If $0.0003 < q_1 = q_2 < 0.0006$, $Q = 0$ if $\mathbf{C} \cdot \mathbf{n}/H \doteq -5/9$. Q is usually actually verified by observations.

Case III: General case Let Q^* be the value Q would have if η were zero. From (15)

$$Q_0 = Q_0^* + s_0 \eta_0 \sec w_0/\epsilon_0 \tag{25}$$

13. *Scale-value*—There are three quantities that might be called "scale-value," differing only in their dependence upon D, namely: $\partial H/\partial n = A$, given by (15); the scale-value to be used in scaling $= s = A\,(n, D_0, t)$, by (11); and the observed scale-value, discussed in section 17. s could include the effect of change of D by rearranging subscripts in (11) or terms in (12), but the above scheme is probably more convenient.

[10] *HIV*, section 44.

[11] F. Horton, On the modulus of torsional rigidity of quartz fibers and its temperature-coefficient, Phil. Trans. R. Soc., **204**, 407-431 (1905), p. 429.

[12] *EMB*, p. 39, line 29.

[13] *HIV*, equation 165, and also An intensity-variometer corrected for temperature, Terr. Mag., **30**, 117-124 (1925).

Turning the torsion-head changes s_0 very little, since only H $(0, D_0, t_0)$ changes. If the base-line value is increased U gammas, the base-line scale-value increases $U\epsilon\tan w_0$ gammas. This is considerably smaller than the change given by Hartnell[14], who apparently did not allow for the change in H_γ in his equation 112 (see also section 26, III).

14. *Change of* ϵ—By (19), $\partial s/\partial n$ involves $d\epsilon/dn$. Frequently this is negligible, but sometimes it is not. ϵ is a function of n alone, determined by where the spot strikes the drum (provided the temperature-compensating device, if any, is very near M). ω (see Fig. 3) is a function of n alone. The effect of lenses upon L can be neglected here[15]. $\tan\omega = n/L$, and $\sec^2\omega\ (d\omega/dn) = 1/L$. If the mirror turns and the compensating device does not (that is, t = constant), $d\omega/dn = 2\partial\theta/\partial n$. Therefore

$$\epsilon = \partial\theta/\partial n = (d\omega/dn)/2 = \cos^2\omega/2L \tag{26}$$

$$d\epsilon/dn = -2\ (\sin\omega\cos\omega/2L)\ (d\omega/dn) = -4\,\epsilon^2\tan\omega \tag{27}$$

15. *a-factor*—This is the designation given by the Coast and Geodetic Survey and others to the coefficient of the first power of the ordinate in the scale-value formula, that is, $a = E\ (n_{\text{mean}}, D_0, t_{\text{mean}})$, to be evaluated from (19) and (27). The ω-term depends upon the position of the spot, whether regular or reserve, while the other terms depend upon the position of the magnet, and are the same for all spots at a given moment. If the values of the arguments are $w = \omega = 0$,

$$a = \epsilon^2(H + \mathbf{C}\cdot\mathbf{n}_o) \tag{28}$$

When $\mathbf{C} = \mathbf{0}$ this confirms the formula of S. E. Forbush[16] rather than that of Hartnell[17]. Distribution effects between compensating magnet and recording magnet may materially alter (28).

What is the "cause" of the principal part of a, given by (28)? The true cause is that (1) is such that $\partial^2H/\partial n^2 \neq 0$, but a more concrete explanation is desirable. One reason given is that "the scale-value depends upon the amount of twist in the fiber, and changes as that amount changes." The equation used was essentially (9), which does contain ψ. This explanation is unsatisfactory, since (9) contains H, w, $\mathbf{n}$, and $\mathbf{p}$, which also vary with n at constant t and D, so that the result is by no means self-evident. In fact, if w be zero, and H then increase, and the torsion-head be turned to bring w back to zero, the twist in the fiber has changed but s has not.

A satisfactory reason is given by (7) in conjunction with (8): One part of s is proportional to the field parallel to the axis, and that necessarily changes when M turns.

16. *Change of s with t*—By (21), $\partial s/\partial t = J$ with $D = D_0$.

Case I: Simple variometer—Since $\eta = \mathbf{C} = 0$, (15) and (21) give

$$C/H = J/A = q \tag{29}$$

for any values of n, D, and t. Since $Q = C\ (0, D_0, t)$ and $s = A\ (n, D_0, t)$, the proportional increases per degree for base-line value and base-line

[14] *HIV*, section 21.

[15] See *DMM*, p. 100.

[16] Some practical aspects of the theory of the unifilar horizontal-intensity variometer. Terr. Mag., **39**, 135-143 (1934), formula 23.

[17] *HIV*, formula 66.

scale-value are *precisely* the same[18]. This effect is small. If $q = 0.0006$/degree, $s = 4\gamma$/mm, and $\triangle t = 20°$, then $\triangle s = 0.048\gamma$/mm.

Case II: No optical compensation ($\eta = 0$)—Consider here only the case where the approximation $w = 0$ is permissible. By (21)

$$\partial s/\partial t = (qk + \mathbf{p}\cdot d\mathbf{C}/dt)\epsilon \tag{30}$$

Note that $k\epsilon$ is the fundamental scale-value, while $\mathbf{C}\cdot\mathbf{p}\epsilon$ is the amount the sensitivity-control magnet increases it. This equation is essentially the same as that given by Hartnell (for his apparatus)[19]. The condition that (30) be zero is equivalent to that given by Schmidt (for his apparatus)[20] that Q be independent of n. (As shown in section 10, the two concepts are equivalent.)

Following the notation of (24), with q_3 referring to the sensitivity-control magnet

$$\partial s/\partial t = [k(q_1 + 0.00016) - \mathbf{C}\cdot\mathbf{p}\ (q_3 + 0.00006)]\epsilon \tag{31}$$

For the unifilar H-variometer at Cheltenham[21], $k\epsilon = 18\gamma$/mm, $\mathbf{C}\cdot\mathbf{p}\epsilon = -15\gamma$/mm. Assuming $q = 0.00037$ and $\mathbf{p}\cdot d\mathbf{C}/dt = -0.00037\ \mathbf{C}\cdot\mathbf{p}$, $\partial s/\partial t = (18 + 15)\ (0.00037) = 0.012\gamma$ mm/degree. This approximates the empirical value of 0.0085, and is not negligible. The large fiber and control-magnet were intended to make $a = 0$, but, as shown by (19), they could have no effect on a unless the axis of the magnet were out of the prime vertical (for then the control-magnet would change $\mathbf{C}\cdot\mathbf{n}$) and then the effect would be slight. But they do produce a large and somewhat uncertain temperature-effect on s.

Case III: Optical compensation ($\eta \neq 0$; *no control-magnets* ($\mathbf{C} = \mathbf{0}$)—If we may approximate by $w = 0$, (21), (23), and (25) give, since $s = k\epsilon$

$$\partial s/\partial t = qs[1 - (H^2/k^2)\ (1 - Q/Q^*)] \tag{32}$$

Every variometer has the term qs, while the rest is due to optical compensation[22]. Physically, change of t at constant $\mathbf{F}$ produces the same change of θ whether or not there is optical compensation. However, with no compensation, the resulting change of s is attributed to change of ordinate, but with optical compensation it must be regarded as change with temperature. In the early work of the Coast and Geodetic Survey with uncompensated unifilar variometers[23] this seasonal change of s was described as change with temperature, and it was only later that it was found to be a change with ordinate (that is, in terms of the experimental variables n, D, and t.)

For small k and large H, the temperature-effect on s may make optical compensation impracticable. If $H/k < \sqrt{2}$, $|\partial s/\partial t|$ is smaller with optical compensation than without it.

[18]Hartnell gives an equation showing that this is approximately true; see Variation of horizontal-intensity variometer scale-value with temperature, Terr. Mag., **36**, 29-32 (1931), p. 31.

[19]See p. 30 of reference 18.

[20]*EMB*, p. 39, line 33.

[21]See p. 32 of reference 18.

[22]The existence of the latter effect was pointed out by W. N. McFarland of the U. S. Coast and Geodetic Survey at a staff-meeting of the Department of Terrestrial Magnetism, Carnegie Institution of Washington, in 1934.

[23]See the first publication for the Baldwin or Cheltenham observatories of the U. S. Coast and Geodetic Survey.

17. *Experimental scale-value*—Scale-values are determined by deflecting the variometer with an auxiliary field produced electrically or magnetically, assumed to be of known magnitude and direction. Let the angle between this field and true north be D'. Let H_0 be the value of H at the moment. By (3) an infinitesimal increment $\mathrm{d}W$ in direction D' produces a change of n given by

$$\sin (D'-\theta)\,\mathrm{d}W = [k+H_0 \cos (D-\theta)+\mathbf{C}\cdot\mathbf{p}+W\cos (D'-\theta)]\epsilon\,\mathrm{d}n \quad (33)$$

To compare $\mathrm{d}W/\mathrm{d}n$ with s (as functions of n, D, and t) note that H in (15) is not the same as H_0 in (33), since in the definition of $\partial H/\partial n$, H changes. If they were in the same direction, $\mathbf{H}$ would equal $\mathbf{W}+\mathbf{H}_0$.

Comparing (15) and (33)

$$s \sin (D_0-\theta)-(\partial W/\partial n) \sin (D'-\theta) = [H \cos (D_0-\theta)-H_0 \cos (D-\theta)-W\cos (D'-\theta)]\epsilon \quad (34)$$

To determine s from observation, we must integrate over the range of n, noting that θ, $\partial W/\partial n$, s, ϵ, H, and W are functions of n. For deflections of usual magnitude, if D, D', and D_0 are within, say, 4° of each other and if $|90°-\theta+D_0|< 5°$, it suffices to write

$$s=(\partial W/\partial n)\,[\cos (D'-D_0)+\cot (D_0-\theta) \sin (D'-D_0)]+\epsilon H\,(D-D_0) \quad (35)$$

and if the angles involved are still smaller, it may suffice to use $s=\partial W/\partial n +\epsilon H\,(D-D_0)$.

Even though no other second-order effects are considered, this correction should be made. If all scale-value observations are made at the same time of day, s should be corrected to mean D, whereas if they are made for different values of D, there will be discrepancies which can be removed by making this correction. At the observatories of the Coast and Geodetic Survey, such discrepancies can easily be 0.03γ/mm.

It might be noted here that a secular change of s is to be expected from the secular change of D_0 (see equation 15)[24].

18. *Spurious effect*—By (15), $\partial H/\partial D=-H \tan w$. By (11) this is to be integrated from D_0 to D, using the values of n and t existing at the moment. The second-order effects given in (12), (17), (20), and (22) will show whether variation of $\partial H/\partial D$ need be considered. If not, evaluate it for some mean values of the arguments. If second-order effects must be considered, evaluate the first-order term for 0, D_0, t_0, using (12) in actual computation.

The F-term is essentially the difference between H and the change of a component in a fixed direction D_0 (see section 24).

The I-terms arise because as soon as H changes the magnet turns, whereupon the effect of change of D is altered. No adjustment except reducing ϵ or increasing s will reduce this error (as contrasted with the first-order effect, which can be eliminated by proper adjustment). Rearrangement of terms in (12) would cause this effect to appear as change of scale-value with declination. If $s=3\gamma$ mm, $H=20{,}000\gamma$, $\epsilon=1/(2000$ mm), $\triangle D=1°$, $\triangle H=150\gamma$, $I\triangle n\triangle D=8.7\gamma$. Hence even small storms cause appreciable errors in H.

The chief part of K comes from optical compensation. In this case, the magnet turns with temperature at constant n, whereupon D affects the magnet as described above.

[24]Discussed by V. H. Ryd in On the scale-value and the base-value of the H-Variometer, Copenhagen, Met. Inst., Comm. Mag., No. 12 (1930), section 6.

With respect to the spurious effect, magnetic compensation is better than optical compensation or no compensation, since in one case K is large while in the other n has large seasonal change. If the above variometer had optical compensation and no control-magnets, with $q = 0.0006$/degree, $\triangle D = 1°$ and $\triangle t = 15°$ would produce an error $K\triangle D\triangle t = 10.5\gamma$ (using 25).

19. *D-variometer*—D is to be a function of n, H, and t. The first-order effects are considered first, and may be found by solving (15) for dD. $\eta = 0$.

20. *Scale-value*—From (15)

$$s = \partial D/\partial n = [1 + (k + \mathbf{C}\cdot\mathbf{p}) \sec v/H]\epsilon \tag{36}$$

s would equal ϵ if the magnet followed the Earth's field exactly. The second term is a small correction. k is about 400γ or 500γ, and is usually considered. $\mathbf{C}\cdot\mathbf{p}$ arises from the other variometer-magnets. For Cheltenham it is about -209γ, and reduces s by about one per cent. This is small, but even smaller corrections are considered, such as the proper method of allowing for the lenses. If k is determined by turning the torsion-head with the Z-variometer in place, ignoring $\mathbf{C}\cdot\mathbf{p}$, the resulting scale-value is approximately $sH/(H + \mathbf{C}\cdot\mathbf{p})$.

That $\mathbf{C}\cdot\mathbf{p}$ must have an effect on s can be seen readily: Suppose $k = 0$. The magnetic axis follows $(\mathbf{H} + \mathbf{C})$. If $\mathbf{H}$ and $\mathbf{C}$ are parallel, the axis lies along $\mathbf{H}$ and $D = \theta$. If D changes, the axis does not lie along $\mathbf{H}$, and $\triangle D \neq \triangle\theta$. Yet torsion-observations with such a fiber give $k = 0$.

If scale-values for H and Z are obtained by deflections with a magnet calibrated on a D-variometer for which $\mathbf{C}\cdot\mathbf{p}$ has been neglected, these scale-values are affected in the same ratio as s. Hartnell[25] discovered this error, but not that for D.

21. *Spurious effect*—From (15)

$$\partial D/\partial H = -(1/H) \tan v \tag{37}$$

Even if $v = 40'$, with $H = 20{,}000\gamma$, $\triangle H$ would need to be 50γ to affect D by $0'.1$.

22. *Temperature-coefficient*—From (15), if $\mathbf{n}\cdot\mathrm{d}\mathbf{C}/\mathrm{d}t = -q_n\, \mathbf{C}\cdot\mathbf{n}$

$$\partial D/\partial t = q \tan v + (1/H)\ (q + q_n)\ \mathbf{C}\cdot\mathbf{n} \sec v \tag{38}$$

For the Eschenhagen D-variometer at Cheltenham, Hartnell[26] computed $\mathbf{C}\cdot\mathbf{n} = -H \tan 12' 36''$. In July 1936 P. H. Williamson of the Coast and Geodetic Survey discovered empirically that $\partial D/\partial t = -0.077'$ per degree. Allowing for temperature-coefficients as large as 0.0007, the author reported (using 38) that such a large coefficient could be explained in terms of known causes only by assuming that $-v$ is excessively large, perhaps $1°.5$ ($H = 18{,}300\gamma$). In September 1936 the direction of the axis was determined as described in section 25 and found to be magnetically north 1° 54′ east. If $q = q_n$, then $q = 0.00055$/degree.

Hence the orientation of a D-variometer may be checked by its temperature-coefficient. The result is subject to a large percentage-un-

[25] G. Hartnell, Test-deflections for variometers and magnetographs, Terr. Mag., 37, 63-77 (1932), section 44, pp. 67-68.

[26] See p. 67, section 43 of reference 25.

certainty, but errors in orientation may often be found more readily in this way than from the spurious effect. In the above case, a change of 60γ in H gives a change of $0'.4$ in base-line value, while a temperature-range of $18°$ gives a range of $1'.4$.

23. *Second-order effects*—These are found by differentiating (36), (37), and (38), noting that D is a function of n, H, and t. In ordinary cases, they are nearly negligible except perhaps the change of s due to obliquity of the drum. Dropping certain still smaller terms, the five second-order effects for which mathematical expressions can be given are

$$(1/2)\ (\triangle H/H)^2 \tan v-(\triangle H/H)\ (\triangle D)\ (k+\mathbf{C}\cdot\mathbf{p})/H-(\triangle H/H)Q\triangle t$$
$$+(\mathbf{C}\cdot\mathbf{n}/H-4\tan\omega)\ (1/2)\ (\triangle D)^2+(qk-q_p\ \mathbf{C}\cdot\mathbf{p})\ (1/H)\triangle D\triangle t \quad (39)$$

where, for convenience, the approximation $s\triangle n=\triangle D$ is made. It is in the smallness of these terms that a D-variometer is superior to an intensity-variometer. If $H=20{,}000\gamma$, $\triangle D=1°$, $\triangle H=150\gamma$, $k+\mathbf{C}\cdot\mathbf{p}=600\gamma$, the second term of (39) is $0'.014$, as contrasted with the error of 8.7γ in an H-variometer (see section 18). Elimination of spurious effects is thus merely a problem of correct initial adjustment.

24. *S-variometer*—To measure variations of S, the component of $\mathbf{F}$ in a fixed direction whose angle with true north is D_2, substitute $H=S\sec(D-D_2)$ and $dH=dS\sec(D-D_2)+S\sec(D-D_2)\tan(D-D_2)dD$ in (15), giving dS in terms of dn, dD, and dt. The theory can be developed as before, remembering that S is a function of n, D, and t.

If $D_2=D_0$ (that is, measuring changes in a fixed direction of the mean declination) the mean values of the second derivatives are the same as for H, except that $F=2H\tan^2 w$ (see section 18).

To measure S as a function of n, R, and t, where R is the component of $\mathbf{H}$ normal to S, put $\mathbf{n}\cdot d\mathbf{F}=\sin(D_2-\theta)\ dS+\cos(D_2-\theta)\ dR$ into (14). The elimination of the variable H from $\partial S\ \partial R$, and the substitution of R for D cause simplification: $F=0$; and $K=0$ if there is no optical compensation. There are, however, other points at which this theory is more complicated than is that of the H-variometer.

25. *Maladjustment*—Often the mean direction of the magnetic axis is in error. Errors may be found by superimposing a field parallel to the desired direction[27]. They may arise: (*a*) From an error in the original set-up (for example, the magnetic and geometric axes may not be parallel); (*b*) from a change in the relation of magnet to mirror; (*c*) from a drift of the spot to a different part of the gram, in the case of an H- or S-variometer; (*d*) from a change of mean declination, in the case of an H-variometer. [At the San Juan Magnetic Observatory, D has changed about $70'$ since the variometers were installed.]

If such a variometer has been used in ignorance of these errors, and the errors are subsequently discovered, what should be done with the records? Only first-order effects are considered.

Suppose we have an H-variometer and have tabulated the supposed differences between H at a moment and a mean H. Call these differences $\triangle H'$. Assume that the auxiliary field used in scale-value observations (section 17) was correct as used (which would not be true if the error in orientation came from cause d). Scale-values were deter-

[27]Discussed in *HIV*, p. 48.

mined experimentally by deflections parallel to mean **H**, and are correct. But $\triangle H'$ must be corrected for the spurious effect by section 18, whence $\triangle H = \triangle H' - H \tan w \triangle D$. If w is large, all values of $\triangle H$ should be corrected.

Frequently w is greater than its uncertainty but not large enough to justify these calculations. But there is another place where it should always be considered. $\triangle X$ and $\triangle Y$ are computed from D, H, $\triangle D$, and $\triangle H$. If w is known to exist it should be used here, since the only additional labor is that of obtaining slightly different formulas, namely

$$\left.\begin{aligned}\triangle X &= \cos D \triangle H' - H \sin 1' \quad (\tan w \cos D + \sin D) \triangle D \\ \triangle Y &= \sin D \triangle H' + H \sin 1' (-\tan w \sin D + \cos D) \triangle D\end{aligned}\right\} \qquad (40)$$

where D is expressed in minutes.

Even with $w = 2°$ the actual errors in $\triangle X$ and $\triangle Y$ through neglecting w are admittedly small. But if D be small, say 6°, if it is worth while to spend 10 hours for an observatory for two years' computations of $\triangle X$, when its value differs from the available $\triangle H'$ by not more than a given amount, it is surely worth the few extra minutes needed to get the correct formula, whose results may differ from the other by one-third of that amount.

This illustrates the method. The actual formulas depend upon the orientation of both H- and D-variometers and the actual direction and magnitude of the field in the scale-value observations, as well as whether any other errors have been found in adopted scale-values.

Suggested improvements

I. Increase optical levers, reducing the angles by which H and Z turn for the same sensitivity, hence reducing spurious effects. The chief obstacle is lack of space in existing rooms.

II. Measure D rather than Y, and X rather than H. A D-variometer is more satisfactory than any intensity-variometer because, when properly adjusted, it responds for practical purposes to change of D only (see section 23). Measuring X rather than H makes F nearly zero (section 24), renders easier the elimination of the first-order spurious effect (section 25d), since, with no optical compensation, the proper position for the light-spot changes only when the relation of magnet, mirror, and light-source changes; and eliminates the need for moving the scale-value apparatus to allow for secular change of D (if this is not done with an H-variometer, $D_0 - D'$ eventually becomes large enough to affect equation (35).

It will be objected that D, X, and Z are not orthogonal coordinates. Such has usually been the case with field-instruments, since D, H, and the dip have been measured.

III. It is desirable to eliminate control-magnets because of the multiplicity and uncertainty of their effects. Some effects on a unifilar variometer can be determined from the equations given herein. But the short distances involved when control-magnets are used cause new problems. There is a net force on the suspended magnet: For the unifilar H at Cheltenham, this force is larger than that of the Earth on one pole. Also, distribution-effects may modify all coefficients appreciably. Adjustment by turning the torsion-head can alter temperature-coeffi-

cient and scale-value, unless the fiber is exactly centered, by bringing the suspended magnet into a different field. I offer two suggestions for possible inventions toward elimination of control-magnets:

III-*a*. Sensitivity-control magnets are usually used because of the difficulty of making a fiber of the proper size. Could a variometer be designed with *length* of fiber adjustable?

III-*b*. A satisfactory substitute for magnetic compensation is needed. As between no compensation, optical compensation, and magnetic compensation, the last is preferable (see section 18). If new materials could be invented for magnet and fiber so that $dk/dt=0$, the problem would be solved. Until then, would it not be possible to have the torsion-head turned by bimetallic strips when the temperature changes[28]?

[28]According to Ryd, see p. 1, reference 24, a similar device has proven satisfactory in the bifilar variometer at Rude Skov.

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ON THE ANNUAL PERIOD OF MAGNETIC ELEMENTS

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As compared with the diurnal variation of the magnetic elements, the annual period is, as we know, rather small. A characteristic of the annual period of the H-component is that it shows a decided semi-annual wave with its minima at the equinoctial seasons, corresponding to the time of the year when the *magnetic activity* is strongest. According to Ad. Schmidt the annual variation is to be interpreted as a vector of force oriented more or less along the magnetic axis of the Earth.

Since the effect of the Earth's revolution about the Sun is clearly discernible in the character of the diurnal variation on quiet days, as well as in the frequency of storminess, it may be supposed that the annual wave in the monthly mean values of the element in question is mainly due to the annual distribution of the diurnal variation.

In a recent publication of the magnetic material collected at the Dombås Observatory[1] we have prepared the tables with a view to affording the best possible opportunity for studying the most characteristic features of the variation, and we have striven to separate the so-called *quiet variation* from that of *storminess*.

The investigation shows that the variation of the D-, H-, and V-curves can each be divided into three variation-components, which we designate as Q, S, and C. The variation-component Q is a relative expression for the *undisturbed progress*, which corresponds in general to the variation of the *international quiet days*. By S we mean *storminess* as defined by Professor Kr. Birkeland. From this component the diurnal variation has been eliminated as far as it is expressed in Q. Furthermore, all the larger periodic waves are eliminated from S—such as the 13.5- and 27-day variation, the annual wave, etc. All the larger periodic waves are represented in the third component C. If this component C be expressed in absolute measure, CGS, and the other two components represent relative data, expressed in γ, we may put $O=Q+S+C$ where O corresponds to the data given in the ordinary publications.

It will be understood that the component Q is corrected for "*noncyclic change*," so that the annual variation of the 24-hour means is eliminated. Although this annual variation of the 24-hour means is well known the annual variation of each individual hour is, on the other hand, more or less unknown, and if it is examined, it is found that each hour has a very characteristic annual variation, which is due to the annual distribution of the diurnal variation. The author had a special interest in examining the annual variation of each hourly value, because we are now engaged in reducing the old *Hansteen series* of 1843-1933 obtained at the Oslo Magnetic Observatory, where the daily record includes only the values at 9^h and 14^h.

When the monthly mean values of the reduced data were plotted, it was found that the annual waves for the two hours mentioned differed considerably in character, and that neither agreed with the known annual wave of the 24-hour means. The publications of other observatories were examined for analogous results but no specific discussion of this subject was found. It seems, therefore, that the following graph may be of general interest.

For the 11-year period 1923-33 for the Dombås Observatory ($\phi=$

[1] O. Krogness and K. F. Wasserfall, Results from the magnetic station at Dombås 1916-33 Bergen (1936).

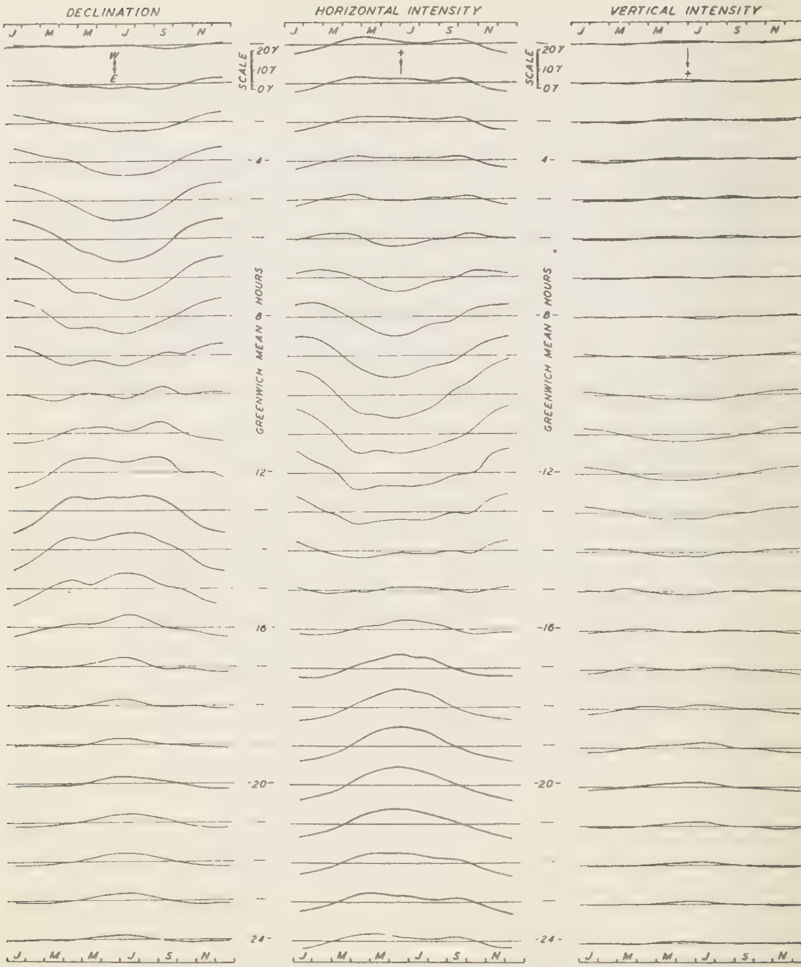


FIG. 1—RESIDUALS BETWEEN THE 11-YEAR MEAN AND THAT FOR QUIET DAYS OF EACH MONTH FOR EACH OF THE 24 GREENWICH MEAN HOURS OF THE DAY AT DOMBÅS, NORWAY, 1923-1933

62° 04′.7 N, λ = 9° 05′.8 E) we have—for each of the 11 years—worked out mean relative data for the diurnal variation of quiet values month by month. These data will be found in the above-mentioned publication. If we now take the 11-year values hour by hour, separately for each month of the year, and then the annual mean, we have all that is necessary to obtain a good average for the annual wave for each hour. In the graph the residuals between the 11-year mean and that for each month have been plotted for each of the 24 hours of the day. The first column at the left gives the result for declination and the next two columns those for the horizontal and vertical intensities.

Det Magnetiske Byrå, *Bergen, Norway, November 1936*

HANSTEEN'S MAGNETIC INSTRUMENT

By K. F. Wasserfall

Hansteen's historic magnetic instrument was, according to old documents, used on but one occasion after his death in 1873. This observation was made by the well-known meteorologist H. Mohn in July 1882. As shortly afterwards a new unifilar magnetometer, Elliott No. 38, was provided, no further attention appears to have been given it.

In 1922 it was decided to undertake the study of the long series of observations with a bifilar at the Oslo Observatory, begun by Hansteen in 1843 and which has continued without interruption until the present time. When the author began the reduction of the series, he found the oscillation-box among some other equipment left by Hansteen but the magnet belonging to the box could not be found. This absolute instrument was very primitive, but the exactness of Hansteen's observations with it is none the less astonishing.

The instrument has been described in detail by Hansteen[1] but, as the reference is not generally accessible, a brief description seems desirable. Recent photographs of it are reproduced in Figures 1 and 2. The mahogany box is 103 mm wide, 122 mm long, and 63 mm high and is supported by three brass foot-screws. Two sliding covers and the long sides of the box are provided with glass windows. The suspension-tube is of mahogany with a removable closed wooden top with screw-thread in wood; the silk fiber was fixed to a brass screw mounted horizontally at the top (see Figs. 1 and 2). The tube is attached to the middle sliding section of the top of the box by a screw-thread in wood.

The distance from the cover of the box to the horizontal brass screw in the suspension-tube is 110 mm; thus the total length of suspension is about 150 mm. There is fixed in the bottom of the box a white paper on which concentric graduated circles are drawn. The graduation is so arranged that the line from 0° to 180° is parallel with the long sides of the box. Inside the box, along one of the windows, is placed a Reaumur thermometer. The magnet completed the outfit.

Observations only of oscillations could be made with this instrument and they were made by eye, there being no telescope. Hansteen observed the time required for 300 (half) oscillations and his observations at the Oslo Observatory from 1843 to 1866 were all made with the same cylinder-magnet; he refers to this magnet as "Dollond's steel cylinder." This magnet was bought as early as 1819 and was manufactured by the London firm Dollond. The cylinder was 72.8 mm long, 2.4 mm in diameter, and weighed 2.67 grams. The steel of the magnet was hardened as much as possible, "as hard as fire and water can make it," according to the statement of the maker.

The mean time-interval for 300 oscillations with Dollond's cylinder at Oslo in 1843 was 812 seconds. The value of its temperature-coefficient as stated by Hansteen shows slight differences in the various references but the logarithmically expressed value adopted by him in later years is $b_s = 14.9$. It appears, however, from the author's investigation that this value is slightly too high. The formula used by Hansteen in the computation of his observations was

$$\log H = C_s - 2 \log T_o$$

[1]Magazin for Naturvidenskaberne, 4, Hefte 3, 271-277, Christiania, 1824.

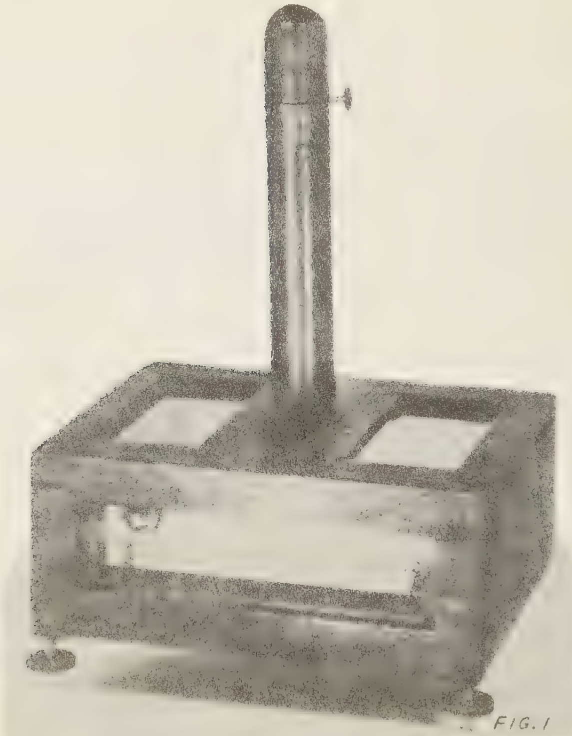
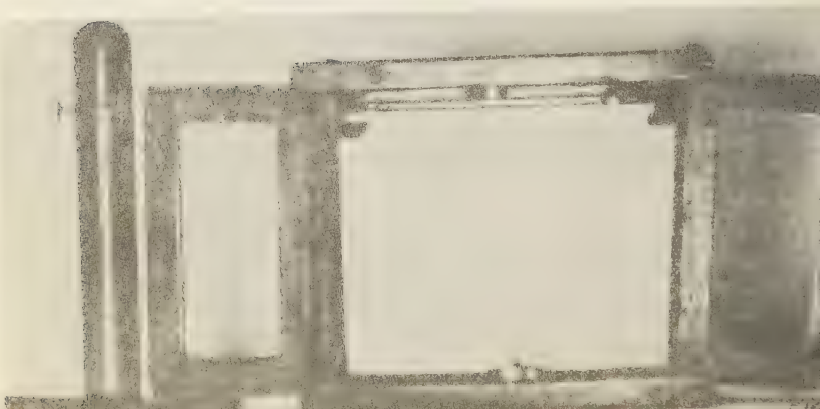


FIG. 1



FIG

where T_0 denotes corrected time for 300 oscillations. Corrections are made for temperature, rate of chronometer, and for reduction to infinitely small arc. As Hansteen used a single silk fiber for suspension, he did not find it necessary to correct for torsion. It is not apparent that a special correction was applied for induction, but the old documents seem to indicate that such a correction was included in the constant C_s.

In 1833 Gauss published a method for the reduction of magnetic observations by the aid of which the data for horizontal intensity could be expressed in absolute measure—the so-called "Gauss unit" ($mm^{-1/2}$ $mg^{1/2}$ sec^{-1}), which corresponds to 0.1 unit in the present CGS system ($cm^{-1/2}$ $g^{1/2}$ sec^{-1}). It may be of interest to mention that the unit used before 1833 was the mean value for the intensity in Peru observed by Humboldt in the year 1799[2]. If for Peru, that is, for the magnetic equator, assuming the inclination to be 0° 00′ and the horizontal intensity to be 1.000, the corresponding values for Paris were 69° 12′ and 1.3482, respectively. On this basis Hansteen calculated the magnetic data for

TABLE 1

Station	Incl'n °	Incl'n ′	Hor. Int.
Peru	0	00	1.0000
Göttingen	69	29	1.3485
Christiania (Oslo)	72	34	1.4578

about 100 stations from which the values given in Table 1 are taken[3]. The basis of the value for the constant C_s of Dollond's cylinder resulted from over 100 observations taken during August and September 1839 at the Göttingen Magnetic Observatory founded by Gauss. In a lecture[4] delivered in May 1859 before the Scientific Society of Oslo, Hansteen said: "By the aid of values for H and T at Göttingen in 1834 and 1839, at Copenhagen in 1845, and seven observations at Christiania (Oslo) in 1840 to 1850, it was found that the value of the constant C_s for Dollond's cylinder had slightly increased, that is, its magnetic moment had undergone a slight decrease."

Further details regarding this instrument and observations made with it by Hansteen will be given in a memoir now in preparation on the complete reduction of the bifilar series at Oslo during 1843 to 1930. It is hoped that this memoir may be completed and published within the next two years.

When Det Magnetiske Byrå in Bergen was established in 1928 and the author was appointed as amanuensis, this historical instrument of Hansteen was placed in his charge and it is carefully preserved in that Bureau as a memorial of its distinguished user in his pioneer work in magnetic research and survey.

[2]Gilberts Annalen der Physik, Stück 3, 1801; Stück 7, 1805.
[3]Magazin for Naturvidenskaberne, 3, 236-253, 1842.
[4]Forhandlinger i videnskabselskabet for 1854, Bind 1858-59.

DET MAGNETISKE BYRÅ,
Bergen, Norway, November 1936

SECULAR CHANGE AT TSINGTAO SINCE 1924

By Chao-Yang Liu

The department of terrestrial magnetism of Tsingtao Observatory was founded some time before the World War, but the records available for the Chinese administration can be traced back only to the year 1924. The magnetograph in use is of Eschenhagen type; it consists of a recording apparatus and a declination-variometer by Toepfer, a horizontal-intensity variometer by Carpintur, and a vertical-intensity variometer by Schulze. The instruments for absolute observations are a magnetometer for both declination and horizontal intensity by Sartorius and a Wild earth-inductor by Schulze and galvanometer for inclination.

So far as the short period from 1924 to 1935 is concerned, the diurnal variations here of the magnetic elements have been found to be not very great. Thus for declination, the absolute differences between the mean values of two successive months never reached 10′, for vertical intensity—except for a few doubtful cases—seldom exceeded 100γ, and for horizontal intensity—the most active and at the same time seemingly also the most sensitive one of the three records—none ever exceeded 100γ.

Table 1 summarizes the annual mean values and the secular changes for the three elements as obtained from the monthly means. For the year 1931 only the absolute observations for horizontal intensity and inclination—whence vertical intensity—are available.

Table 1—*Annual mean values and secular changes, Tsingtao Observatory, 1924-35*

Year	Annual mean values			Secular changes		
	Decl'n[a] D	Hor. int. H	Ver. int.[a] Z	D[a]	H	Z[a]
	° ′	γ	γ	′	γ	γ
1924	−4 21.3	30816	39609			
				−1.3	+15	− 6
1925	−4 22.6	30831	39603			
				−4.4	− 8	+147
1926	−4 27.0	30823	39750			
				−2.8	+ 1	−123
1927	−4 29.8	30824	39627			
				−0.3	+13	+ 71
1928	−4 30.1	30837	39698			
				−2.5	+19	− 15
1929	−4 32.6	30856	39683			
				−0.2	+12	− 16
1930	−4 32.8	30868	39667			
				+0.7	+12	− 19
1931	−4 32.1	30880[b]	39648[b]			
				0.0	+12	+ 14
1932	−4 32.1	30892	39662			
				−2.0	+ 9	+ 13
1933	−4 34.1	30901	39675			
				−0.8	+18	+ 22
1934	−4 34.9	30919	39697			
				−1.7	+ 4	+ 17
1935	−4 36.6	30923	39714			

[a]East declination and north inclination being reckoned positive. [b]Absolute observations only.

The Observatory is in latitude 36° 04′ 11″ north and longitude 120° 19′ 14″ east at an elevation of 78 meters above sea-level.

Tsingtao Observatory, *Tsingtao, China*

SUDDEN IONOSPHERIC DISTURBANCES*

By J. H. Dellinger

This paper presents a summary of the data and conclusions up to this time of an investigation, started about the middle of 1935, of a comparatively new phenomenon. The phenomenon is the occurrence of a sudden intense increase in the ionization of a portion of the ionosphere, with resultant transient disturbances in such phenomena as radio-wave transmission, terrestrial magnetism, and earth-currents. The effects last for a period ranging from a few minutes to an hour or more. The whole phenomenon is of scientific interest particularly because it appears to have its origin in sudden bursts of radiation from the Sun, and is opening the way to increased understanding of the Sun, the ionosphere, radio transmission, terrestrial magnetism, and related phenomena.

Occasional examples can be found in old records of effects which may be interpreted as manifestations of this phenomenon, but its existence as a specific phenomenon was recognized less than two years ago. In October 1935 the author published[1] a brief account of four occasions on which all high-frequency radio transmission throughout an entire hemisphere was suddenly silenced. He pointed out that the effects occurred throughout the illuminated half of the globe and not the dark half, advanced the hypothesis that they depend on some solar emanation lasting only a few minutes, and suggested observations by workers in other sciences with a view to learning of the possible occurrence of effects in terrestrial magnetism, solar radiation, etc., simultaneous with radio fade-outs. The suggestion met with wide-spread interest[2], and the author has had the collaboration of numerous individuals and organizations in this investigation.

Evidence followed rapidly that the postulated simultaneous effects do occur. The astronomers at the Mount Wilson Observatory of the Carnegie Institution of Washington were asked to examine their spectrohelioscopic data for the dates in question, and in November, 1935, informed the author that a bright eruption had been observed on the Sun within a few minutes of the time of each of the radio fade-outs during which solar observations had been in progress.

The magnetograms of the Cheltenham, Maryland, Observatory of the United States Coast and Geodetic Survey were examined, and small abrupt pulses in horizontal intensity and declination were found for the time of the July 6, 1935, radio fade-out, beginning within two minutes of the fade-out time. It was reported to the author that a large sharp pulse had appeared on the earth-current recorder of RCA Communications, Inc., on the same date within a few minutes of the radio fade-out.

*Publication approved by the Director of the National Bureau of Standards of the United States Department of Commerce.

[1]Science, 82, 351 (1935); Phys. Rev., 48, 705 (1935).

[2]O. W. Torreson, W. E. Scott, and H. E. Stanton, Terr. Mag., 41, 199-201 (1936); R. S. Richardson, Ter. Mag., 41, 197-198 (1936); O. W. Torreson, F. T. Davies, W. E. Scott, and H. E. Stanton, Terr. Mag., 41, 409-410 (1936).

From these beginnings has grown an extensive research upon these interrelated phenomena. Through the kindness of many cordial cooperators I am able to present in Table 1 a very condensed summary of data on the known occurrences for 1934-36. They are in part based upon automatic records of radio field-intensity and automatic ionospheric echo-records made continuously by the National Bureau of Standards, and in part upon reports from numerous organizations and individuals. The reports are relatively meager for the Asiatic and Pacific regions. It is believed that the results are of sufficient value to provide an encouragement for more thorough future work in this field.

Table 1—*Reported occurrence of fade-outs and associated phenomena, 1934-1936*

Date	Beginning of fade-out GMT	Other effects at same time[a]	Date	Beginning of fade-out GMT	Other effects at same time[a]	Date	Beginning of fade-out GMT	Other effects a same tim
1934	*h m*		*1936*	*h m*		*1936*	*h m*	
Nov 28	17 10*	SME	Apr 29	01 00	......	Jun 19	20 18	......
1935			29	05 00	......	25	10 40	S
Jan 25	03 35	......	30	09 40	......	25	11 15	S
Mar 20	01 48	......	May 8	20 20	ME	Jul 15	13 25	SM
May 12	11 57	ME	14	17 52	......	31	00 15	S
Jul 6	14 08*	SME	15	05 55	......	31	09 30	......
Aug 30	23 20	S	25	12 35*	ME	Aug 4	17 27	SM
Sep 13	16 30	S	26	11 30	S	5	16 07	SM
27	12 48	M	27	03 50	M	8	17 25	S
29	20 55	M	27	23 45	......	23	11 30	M
Oct 24	11 00	E	28	03 40*	......	25	18 30*	SME
Nov 18	17 55	......	28	07 30*	SM	28	09 30	S
29	14 05	S	28	14 00*	......	Sep 4	01 45	S
30	18 55	......	28	18 00*	M	4	12 38	......
Dec 16	22 23	S	29	10 25	......	4	17 14	ME
17	16 15	SM	30	17 30	M	5	09 02	M
18	04 50	......	Jun 3	00 50	......	Oct 9	14 24	......
23	17 40	S	3	16 35*	SM	16	17 35	......
1936			3	18 25	M	21	15 35*	ME
Feb 6	15 20	M	4	04 40	M	Nov 3	18 55	M
8	01 30*	......	4	11 55*	M	6	16 10*	SME
8	13 28	SM	5	02 36	M	7	03 45	......
14	15 18*	SM	9	14 24*	......	7	14 50	S
16	15 50	S	9	15 55	M	8	18 19	SM
Mar 4	19 56	ME	9	17 50	M	8	21 47	......
10	05 40	......	9	19 00	M	16	15 00	S
23	15 45	SM	10	20 55*	M	19	04 45	......
Apr 1	09 30	S	11	06 25	......	24	17 10	......
1	12 00	......	11	12 30	......	24	19 14*	SM
2	04 05	......	16	13 30*	SM	25	19 25	......
6	13 55*	M	16	17 15	SM	26	09 00	......
7	01 10	SM	16	18 00*	M	26	17 50*	S
7	02 30	S	17	07 23	S	27	16 51	SME
7	04 15	......	17	09 08	......	29	15 47	S
8	09 20	SM	17	12 48	......	Dec 3	12 10	S
8	14 50	M	19	09 10*	S	21	18 20	......
8	16 45*	SME	19	16 20	M	24	22 05	S
9	13 20	S	19	17 30	S	24	23 50	S
25	14 27	S	19	19 38	S	26	19 38	......
25	16 53	SM						

[a] *S*, *M*, and *E* denote simultaneous observation of solar eruption, magnetic pulse, and earth-current pulse, spectively.

*Indicates the more intense effects.

More complete information on these occurrences and discussion of their significance will be published in the *Journal of Research of the National Bureau of Standards*. The data represent very extensive observations, but even so do not give comprehensive information on the occurrences. In some cases we have knowledge of the disturbance from only two places. Effects reported from only one place are not included. For the more intense effects, the time is indicated by an asterisk.

It would be desirable to have for each case information from numerous points all over the world, on the effects which occurred in radio transmission, terrestrial magnetism, and earth-currents. The incomplete character of our knowledge should be remembered in interpreting the data. It is hoped that publication here will provide information of interest to scientists who have records that might give additional information.

The radio, terrestrial-magnetic, earth-current, and solar effects are all simultaneous with one another, and the whole phenomenon lasts usually from ten minutes to an hour. The radio effect is the sudden cessation of high-frequency radio signals received from a distance, or the disappearance of echo-pulses in ionospheric experiments. The terrestrial-magnetic and earth-current effects are the occurrences of a sudden sharp increase or decrease of a recorded element, followed by return to normal; the terrestrial-magnetic effect is usually more marked in the horizontal intensity than in the vertical intensity or declination. The solar effects listed in the table are bright eruptions of the type regularly reported in the quarterly *Bulletin for Character-Figures of Solar Phenomena* from Zurich. The simultaneity of the solar effect with the other effects is not usually as exact as the simultaneity of the latter with one another. The radio, terrestrial-magnetic, and earth-current effects are simultaneous in their beginning within a few minutes; this is true of the solar eruptions in some cases; but in others the time of the solar effect merely overlaps some part of the time of the other effects. This is in part because of considerable uncertainty as to the times of many of the solar eruptions; they are sometimes seen with difficulty and the observing astronomer can not be sure when a disturbance begins or ends; reports of the time of occurrence of a given eruption as observed at different observatories sometimes give differences of more than 15 minutes.

It is clear from the nature of the several terrestrial effects that they are caused by a sudden increase in ionization in some portion of the ionosphere, caused in turn by electromagnetic waves from a solar eruption. The geographical distribution of the effects, for example, accords very well with this hypothesis; their intensity is greatest in that region of the Earth where the Sun's radiation is perpendicular and diminishes to zero at the boundary of the illuminated hemisphere. The effects are thus more intense where it is noon than at other times of day, and are more intense in equatorial regions than in higher latitudes.

An increase in the ionization of a layer in the ionosphere may have two effects on radio transmission, namely, (*a*) it raises the upper limit of frequency of radio waves which it is able to reflect, and (*b*) it absorbs the radio waves' energy and thus diminishes received intensity of waves which pass *through* the layer. Effect (*a*) has not been observed to occur during these sudden disturbances and (*b*) occurs every time. Furthermore, as the energy-absorption takes place for radio waves reflected

from each of the three layers well known to be effective in high-frequency radio transmission, it follows that it occurs at some level below the lowest of these layers. The seat of the phenomenon is therefore a region below the *E*-layer, that is, less than 110 kilometers above the Earth's surface.

The variation of the radio effects with frequency is in harmony with this explanation. Also, there has been evidence in some of the sudden disturbances that the intensity of reception on frequencies lower than the broadcast-band has improved rather than diminished. This indicates that the radio waves of low frequencies do not pass through this lower region but are propagated by means of reflection from it rather than from the *E*-layer. This lower region thus reflects low frequencies and causes absorption of frequencies above the broadcast-band. The effective region may be at different heights in different occurrences of the phenomenon.

These characteristics of the ionospheric disturbances, thus deduced from the radio effects, throw some light on the associated phenomena. For example, the concomitant terrestrial-magnetic perturbations are clearly seen as a separate type not recognized prior to this investigation.[3] They have their seat below the *E*-layer. The effect is a maximum in localities of low latitude and near noon, and does not occur on the dark side of the Earth. They are strikingly different from the perturbations occurring in so-called magnetic storms. A magnetic storm lasts many hours or days rather than the brief period of the disturbances here studied; its commencement is simultaneous over the whole Earth instead of occurring only in the illuminated hemisphere; and its distribution in latitude is the opposite of that of the disturbances here studied.

Radio effects during magnetic storms indicate that the ionic density of the F_2-layer is reduced and the ionization diffused rather than sharply stratified. Thus the two kinds of magnetic phenomena are seated in entirely different portions of the ionosphere, in entirely different ways, and are probably due to two different kinds of ionizing agents. We thus have a new tool for analysis of the characteristics of terrestrial magnetism and for determination of its causes. The facts cited indicate that the vast ionospheric current-systems which cause the fluctuations of terrestrial magnetism involve both the F_2-layer and the region below the *E*-layer. The location of these current-systems thus becomes more definite than in speculation hitherto. Further study of the ionosphere and of the sudden ionization should do much to bring to light the hitherto unknown mechanisms of terrestrial-magnetic variations.

The acting cause of the sudden ionization is strikingly different from the acting cause of the ionization in the recognized *E*-, F_1-, and F_2-layers. Assuming the former cause to be a sudden burst of radiation from the Sun, it must be of sufficiently penetrating character to come through these layers and produce great ionization at a lower level where the mean free-path is short enough to insure numerous collisions of moving ions and hence rapid absorption of the radio-wave energy. This explains both the great reduction of the radio-wave intensity and the short duration of the effect. The ionization at this level disappears extremely rapidly by recombination after the acting cause ceases.

Only a fraction of the visually observed solar eruptions is accompanied by sudden disturbances in our ionosphere. This is not surprising,

[3] J. A. Fleming, Terr. Mag., **41**, 404-406 (1936); A. G. McNish, Nature, **139**, 244 (1937).

since the radiations causing the ionospheric effects are of wave-lengths much shorter than visible light. Some solar eruptions which emit visible radiation also emit the type of radiation which causes sudden ionospheric disturbances and some others do not.

The ionospheric disturbances and their associated effects are the only means of detecting the causative radiation, because this radiation does not penetrate down to the Earth's surface and thus can not be directly detected by any instrumental means. We have thus come into possession of a means of studying a class of invisible solar radiation not hitherto accessible to detection or measurement. Further study of these and the other classes of radiation affecting the ionosphere should be fruitful in extending our knowledge of phenomena on and in the Sun.

Summarizing, this investigation has revealed and explained the occurrence of a special type of sudden disturbance in the ionosphere. Data are given on the known 115 occurrences of the phenomena in the past two years. The disturbance is always manifested by abnormal absorption of high-frequency radio waves and frequently also by perturbations of terrestrial magnetism and earth-currents. The disturbance is due to sudden abnormal ionization of a region below the E-layer. Geographical distribution and other characteristics of the effects clearly indicate solar eruptions as the source of a radiation causing the sudden abnormal ionization. This is a different category of radiation from those causing the ionization of the E-layer and higher layers. Further study of the sudden ionospheric disturbances give promise of increased knowledge of the mechanisms of radio-wave transmission, terrestrial magnetism, earth-currents, and solar eruptions and sunspots.

National Bureau of Standards,
Washington, D. C., March 4, 1937

REVIEWS AND ABSTRACTS

O. Krogness and K. F. Wasserfall: *Results from the magnetic station at Dombås 1916-33.* Bergen, Pub. Inst. Kosmisk Fysikk, Nr. 9, 110 pp. (1936).

Publication of a lengthy series of magnetic observations is always an event in the history of terrestrial magnetism, particularly if, as in this case, the observations were made in a region of unusual interest. To one familiar with the process of reducing magnetic data this publication bespeaks many inglorious and tedious but fundamentally important hours of labor on the part of the authors.

Tables are given for "7-day normals" for quiet diurnal variations in declination and horizontal intensity only, and monthly mean values for quiet diurnal variation, monthly mean values for diurnal variation in storminess, and daily values for positive, negative, and absolute storminess in declination, horizontal intensity, and vertical intensity. Treatment of the data in this way follows methods employed by Birkeland in his investigations of terrestrial-magnetic phenomena at the beginning of this century. Graphs appropriately illustrating the tables are included in the volume.

The advisability of treating the data in this manner is open to question. The "7-day normals" are obtained by adding together the curves on seven successive days, discarding the disturbed hours in each day and interpolating through that interval. Although when treated in this way the data are more easily used in certain specialized studies, many other studies are thereby rendered impossible. Undoubtedly most investigators will agree that the publication of hourly values as observed, daily means, and hourly means for the several classes of days is preferable, special arrangements of the data being performed by the individual to meet the needs of his own researches.

A. G. McNish

H. Ertel: *Advektiv-dynamische Theorie der Luftdruckschwankungen und ihrer Periodizitäten.* K. Stumpff: *Ueber die Zufallswahrscheinlichkeit von Periodizitäten in Beobachtungsreihen.* O. Schneider: *Einflüsse der Sonne auf die lunare Variation des Erdmagnetismus.* H. v. Ficker: *Die Passatinversion.* Veröffentlichungen des Meteorologischen Instituts der Universität Berlin, Band 1, Hefte 1-4. Berlin, Verlag von Dietrich Reimer, 31, 54, 43, and 33 pp., respectively, 1936, 22 cm.

These pamphlets constitute the first four publications of the Meteorological Institute of the University of Berlin. The first, by H. Ertel, deals with the advective-dynamic theory of variations of air-pressure and their periodicities. In a rational theory of the space-time variations of an atmospheric-pressure field, the advective and dynamic effects must be equally taken into consideration. In the present paper an attempt is made to develop such a theory of the atmospheric-pressure field and its variations starting from the concept deducible from the hydrodynamical equations, that every space-time change of the pressure-field consists in an irreversible deformation brought about by advective-dynamic processes.

In the second paper, K. Stumpff discusses the random probability of periodicities in series of observations—the fundamentals of a general expectancy-theory. The Schuster theory of expectancy is only useful in determining the reality of observation-series, when the individual observational values are independent of each other—a condition seldom fulfilled in practice. An attempt is made to build up the theory on broader foundations so that it may be used as a criterion for determining the reality of periods in cases where "conservation" or "interdependence" of successive data exists. Special assumptions are also made here which in reality are not always fulfilled but the applicability of the theory is considerably extended and the way to its complete development opened.

In Heft 3, O. Schneider reports on a statistical investigation of the effect of the Sun on the lunar variation of terrestrial magnetism using as data two observational series from the Huancayo and Batavia magnetic observatories situated near the equator. A detailed description of the methods used is presented together with a discussion of the results which are somewhat in disagreement with Chapman's conclusions that lunar and solar diurnal variations are differently affected by magnetic activity.

H. v. Ficker discusses in the last paper the heights of the trade-wind inversion over the Atlantic Ocean on the basis of all available data, utilizing particularly the observations obtained on the *Meteor* expedition 1925-27.

H. D. Harradon

FURTHER STUDIES ON THE VERTICAL MOVEMENTS OF THE AIR IN THE UPPER ATMOSPHERE

By Leiv Harang

Introduction—In a previous paper[1] a number of observations partly of auroras and partly resulting from ionospheric studies were discussed and it was shown that a considerable diurnal temperature-variation from night- to day-conditions must exist at heights of and above 100 km. The following paper contains a discussion of the same subject supported by further observations. At the end of the paper a summary and discussion of the critical-frequency determinations at noon of the ionized regions during April 1935 to November 1936 by the Breit and Tuve pulse-method are given.

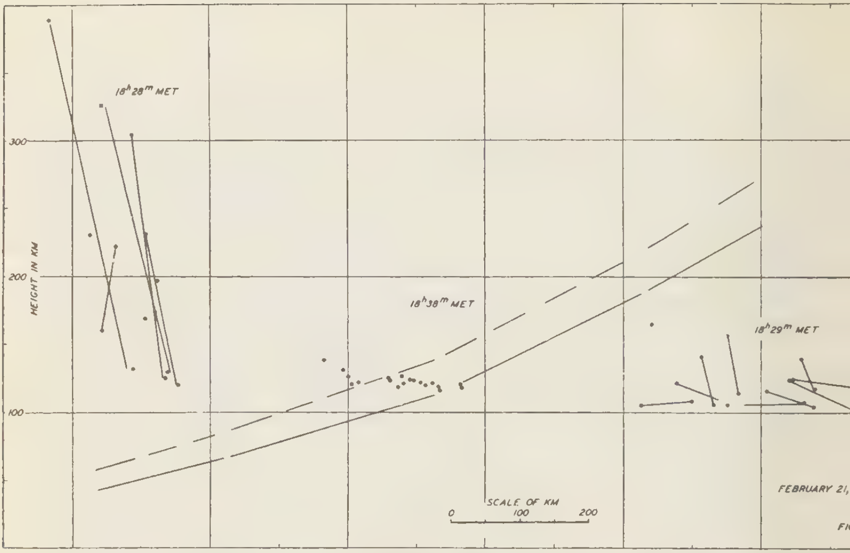
§1. *Further evidence of diurnal temperature-variations at the height of 100 km as deduced from measurements of auroral heights* In the above-mentioned paper[1] the height-measurements of an auroral arc 800 km long were given, for which one-half was in the shadow and the other was in the sunlit atmosphere. The heights of the lower border of this arc were uniformly 100 km in the dark atmosphere, whereas the heights in the sunlit atmosphere increased continuously from 100 km to about 140 km. Assuming the penetrating power and the geometry of the paths of the electrically charged particles to be the same along the arc, the continuous increase of the auroral heights indicates the position of an isobaric surface in the atmosphere. The lifting of this isobaric surface in the sunlit atmosphere which corresponded to an elevation of $\tan \phi = 0.1$ must be regarded as an effect of the expansion of the atmosphere due to heating by the Sun's rays.

During the spring of 1936 a number of auroras appearing in the afternoon were photographed simultaneously from the Observatory in Tromsö and from our second station Tenness, 43.4 km to the south. In this paper a selection of the height-determinations of auroras lying at the border between the sunlit and dark atmosphere will be given. Figure 1 shows the position of auroras relative to the Earth's shadow as determined from three series of pictures taken February 21, 1936. The auroras photographed in the west at $18^h\,27^m\,32^s$ to $18^h\,28^m\,33^s$ MET consisted of sunlit rays and draperies. The maximum height attained was 389 km; the lower limit was 120 to 130 km. At the same time a drapery-shaped band appeared in the east, the lower limit of this determined from three pairs of photographs taken between $18^h\,29^m\,11^s$ and $18^h\,29^m\,39^s$ MET was 105 to 110 km and the maximum height attained by the streamers was 160 km. About nine minutes later a very intense drapery-shaped band appeared in the west, much nearer Tromsö than the group of draperies first photographed. The heights of the lower border determined from nine pictures taken between $18^h\,37^m\,24^s$ and $18^h\,38^m\,35^s$ MET were 120 to 130 km. The band was partly sunlit and as shown in Figure 1, the heights of the lower border decrease as they approach the shadow-line.

Two shadow-lines in this and the following Figures have been computed. For the upper broken line the effect of atmospheric refraction has been neglected but for the lower one it has been considered[2].

[1]Terr. Mag., **41**, 143-160 (1936).

[2]In this and the following Figures the Earth's surface is drawn as a plane. Moreover, a different scale in horizontal and vertical directions is used, the latter being made twice the former in order to demonstrate more distinctly the height-variations of the auroras. As a result of this the shadow-lines in this and the following Figures are not straight lines.



We consider that the increasing heights of the lower border and the increasing vertical extension of the auroras, proceeding from the dark to the sunlit atmosphere, as illustrated in Figure 1, are chiefly due to different densities of the upper atmosphere, the expansion of the sunlit part being caused by the heating effect of the Sun's rays.

The gradual increase of the auroral heights from the dark to the sunlit atmosphere is also illustrated in Figures 2, 3*A*, and 3*B*. Figure 2 shows the heights of sunlit bands as determined from four photographs taken February 23, 1936, in the interval $18^h\ 28^m\ 10^s$ to $18^h\ 28^m\ 54^s$ MET, and, for comparison, the heights of auroral bands lying in the shadow as determined from four pairs of photographs taken between $19^h\ 56^m\ 57^s$ and $19^h\ 57^m\ 55^s$ MET. Figure 3*A* shows the heights of a partly sunlit auroral arc with ray-structure as determined from four pairs of photographs taken March 3, 1936, between $20^h\ 53^m\ 55^s$ and $20^h\ 54^m\ 26^s$ MET; Figure 3*B* shows the position of a diffuse double arc penetrated by a faint ray as determined from four pictures taken in the interval $21^h\ 15^m\ 40^s$ to $21^h\ 17^m\ 33^s$ MET.

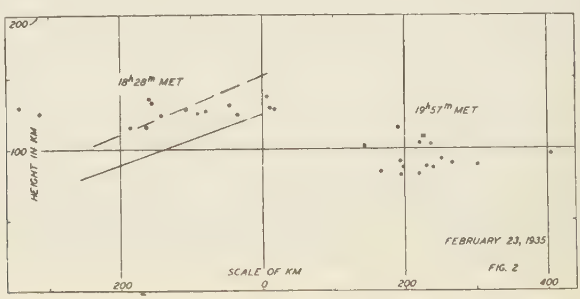


FIG. 2

In the previous paper[1] the increase in temperature of the atmosphere at height 100 km from the dark to the sunlit part in the border-region was estimated, on the assumption that the lower border of the auroras indicated an isobaric surface. It was shown in the case considered that a proportional increase in the absolute temperature of 1:1.57 was necessary to explain the lifting of the auroral heights in the sunlit atmosphere. In the series of observations here given the increase of the auroral heights from the dark to the sunlit part of the atmosphere is of the same magnitude, and an estimate of the temperature-increase will give values of the same magnitude as computed in the first paper.

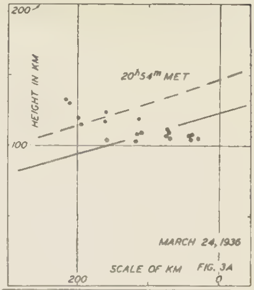


FIG. 3A

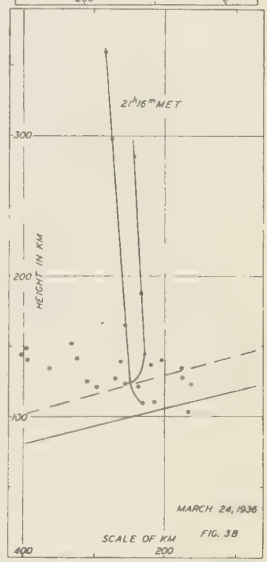


FIG. 3B

Concerning diurnal temperature-variations in the lower part of the stratosphere, the study of the diurnal variations of the ozone-concentration as well as the study of the refracted sound-waves should yield information. Direct measurements of temperature in the lowest part of the stratosphere up to 20 km by sounding balloons have shown that this part of the stratosphere exhibits temperature-variation with season as well as with latitude. As to the diurnal variation of temperature in the part of the stratosphere up to 20 km, it is difficult to determine since the main temperature varies with the changing air-masses, but the observations indicate that any diurnal variation must be small. Sir Napier Shaw summarizes the results of the observations of the diurnal temperature-variations as follows[3]: "Nothing, above a kilometer, can be called diurnal variation in the sense used about the surface." There thus seems to be a fundamental difference between the diurnal variation of temperature in the lower and upper regions of the stratosphere, a difference which is due most probably to a difference in absorption of the solar spectrum at different heights of the atmosphere.

§2. *Diurnal electron-density curves during winter at high latitudes; the magnitude of the coefficient of recombination in the F_2-layer*—As shown by Appleton[4] the maximum electron-density in a layer can be determined by means of the critical frequencies, that is the limiting penetrating frequencies. In high latitudes where the direction of propagation at vertical incidence nearly coincides with the direction of the Earth's magnetic field, a signal is split up in the ionized layer under the influence of the Earth's magnetic field into two circular polarized components, ordinary (o) and extraordinary (x), with opposite senses of rotation. The maximum

[3]Manual of Meteorology, 2, 111 (1928).
[4]Nature, 127, 189 (1931).

electron-density (N) is determined by the following equations, taking the polarization-term into account

$$N=(3\pi/2)\ (m/e^2)\ f^2\ (o\text{-component})$$
$$N=(3\pi/2)\ (m/e^2)\ (f^2-ff_H)\ (x\text{-component})$$

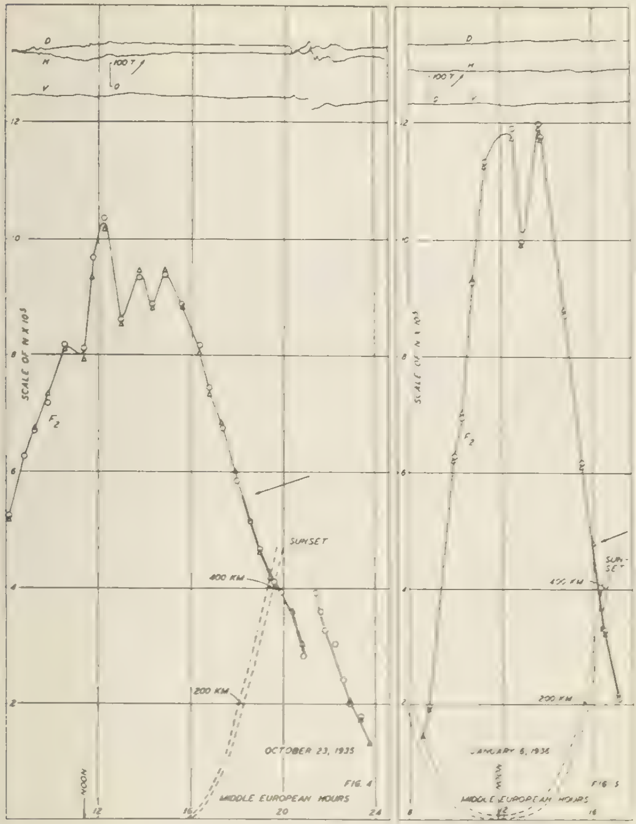
Figures 4, 5, 6, and 7 show the diurnal variation of electron-densities computed from the critical frequencies[5]. For details of the experimental arrangement, we refer to the first paper[1]. The critical frequencies were determined by recording the echoes appearing in a frequency-interval 1.3-10 mgc/sec, usually every 30 minutes or even at shorter intervals. For the F_2-layer the electron-densities N, computed from the o- and x-components, are indicated by open circles and triangles. For the E-layer the observed critical frequency is assumed to be the ordinary component; the computed electron-densities are indicated by open squares. The times of sunset at different heights are shown by broken lines, the double line indicating the heights with and without taking the effect of refraction into account. The equivalent (or virtual) heights of the points of reflection for different frequencies are shown at the bottom of Figures 6 and 7—the group-velocity of the signals is here assumed to be equal to the velocity of light. The magnetograms from the Observatory are reproduced at the top of each figure.

In a region as highly disturbed magnetically as Tromsö, which is near the auroral zone, it is difficult to obtain diurnal electron-density curves free from the effects of magnetic perturbations. One must also consider magnetic perturbations occurring at night as caused by the perturbing current-systems following the auroral zone in the upper atmosphere. The effects on the ionosphere caused by the magnetic perturbations is therefore to be ascribed to current-systems which exist at or near the place of observation.

A detailed analysis of the echoes occurring during the night of January 29-30, 1936, was made and Figure 6 shows a number of these effects. The results of an analysis of this day are as follows: After a magnetically undisturbed day with smooth electron-density curves for the E- and F_2-layers, the small secondary maximum appears at $15^h\ 30^m$ MET; this is explained as evening concentration caused by the shrinkage of the F_2-layer at sunset. After sunset the F_2-ionization decreases very rapidly. The magnetic storm now commencing is attended by the appearance of an E-layer, which is usual during magnetic storms of moderate intensity[6]. Shortly afterward a high F-layer is formed. As previously shown[1] these high F-layers which are formed during and after magnetic storms must be regarded as effects of an expansion of the upper part of the F_2-layer during the storm. After the storm the upper atmosphere contracts and layers are formed. These layers sink continually, their vertical displacement being thus the opposite of the normal F_2-layer during the afternoon and evening. As shown in Figure 6, this high F-layer at about 20^h shows rapidly decreasing heights of the reflecting points for five and six mgc sec. The more intense perturbation at about $21^h\ 20^m$ and at 23^h to 24^h is accompanied by a complete cessation of echoes on all wave-lengths. The absorbing layer[6] below the E-layer which appears during intense

[5]A number of electron-density curves for different seasons have been published in Beitr. Geophysik, **46**, 438-454 (1936).

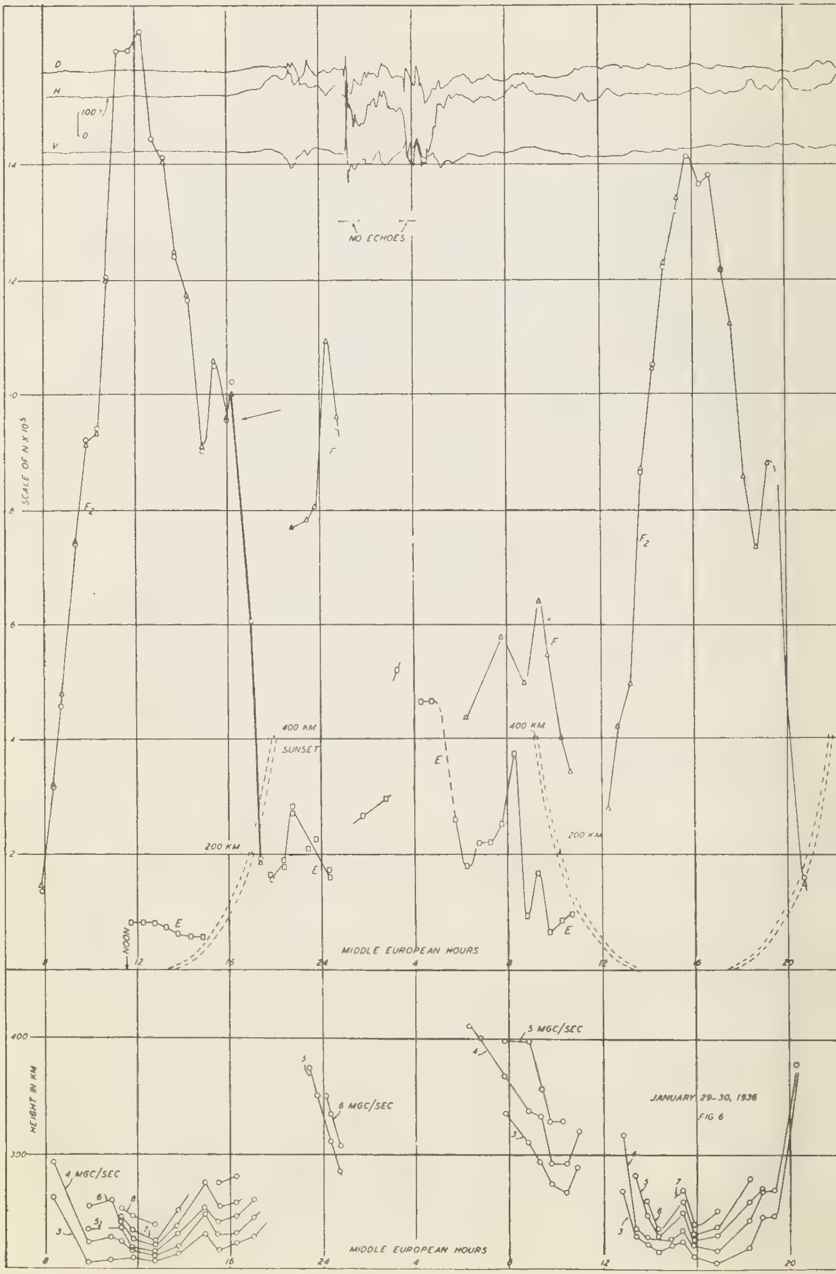
[6]E. V. Appleton, R. Naismith, and G. Builder, Nature, **132**, 340-341 (1933).



magnetic storms, is now formed. This more intense phase of the storm ends at about $1^h\,20^m$; the E-layer with a number of stratifications is now present. At about 2^h the high F-layer again appears. The critical frequencies vary irregularly, but the heights decrease continuously during the early morning hours and at sunrise the layer sinks into the normal F_2-layer. This gradual development of the ionized layers during magnetic storms has been confirmed by similar analyses on a number of nights during the last two winters.

The diurnal electron-density curve for the F_2-layer should afford data for an estimate of the magnitude of the recombination-coefficient in the layer. After sunset when the ion-production has ceased, the recombination between the positive ions and the negative electrons is determined by the equation $(dN/dt) = -\alpha N^2$ where α is the coefficient of recombination. A second process which also reduces the concentration of electrons is the attachment of electrons to neutral molecules. In the discussion of Appleton and Naismith[7] on the seasonal variations of the

[7]Proc. R. Soc., 150, 685-708 (1935).


D
H
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SCALE OF N X 10^5
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12
10
8
6
4
2
F2
F
E
400 KM
SUNSET
200 KM
NOON
MIDDLE EUROPEAN HOURS
8
12
16
24
4
8
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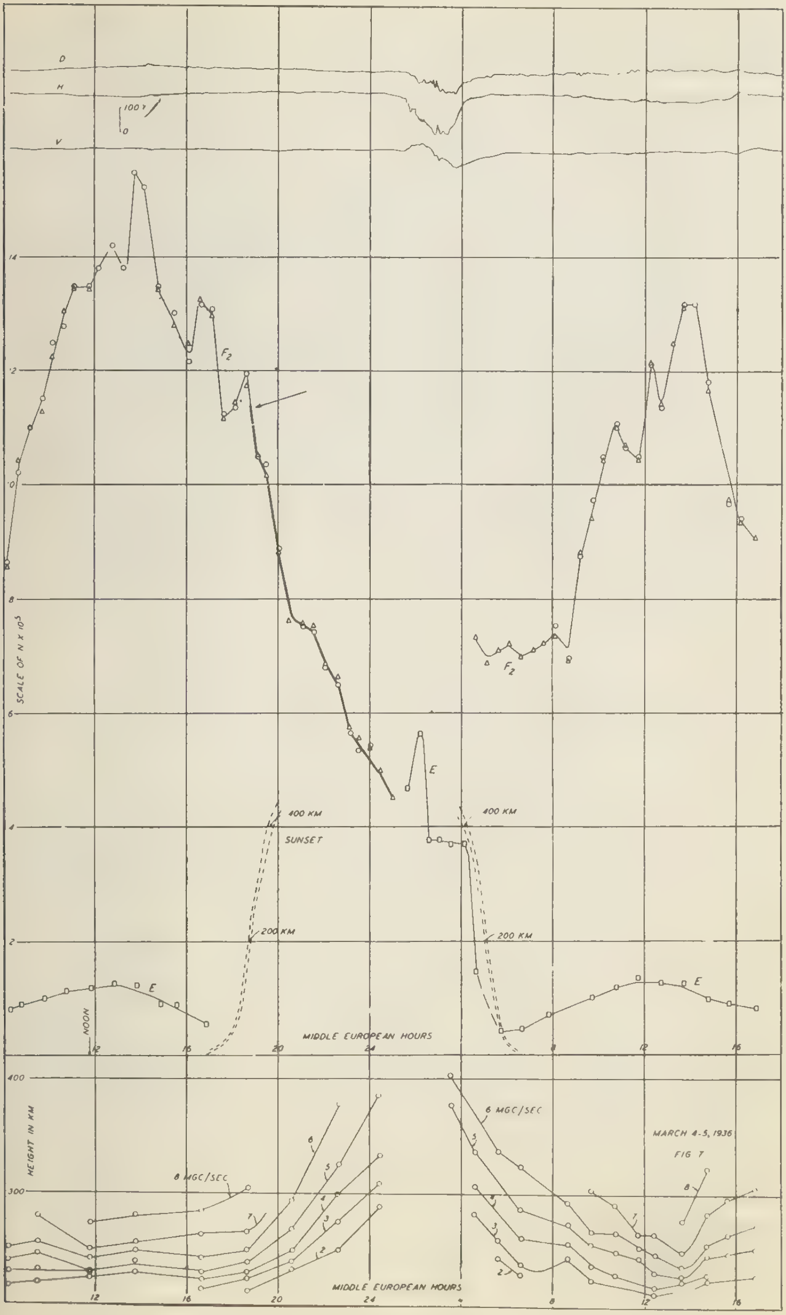
20
HEIGHT IN KM
400
300
4 MGC/SEC
5 MGC/SEC
6 MGC/SEC
JANUARY 29-30, 1936
FIG 6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200 KM
NOON
12
16
20
24
8
12
16
MIDDLE EUROPEAN HOURS
400
300
HEIGHT IN KM
6 MGC/SEC
8 MGC/SEC
MARCH 4-5, 1936
FIG 7

critical frequencies it was shown that the process of recombination is most probably the predominant one in electron-dissipation, the attachment of electrons to neutral particles being of minor importance.

For our purpose it is more convenient to write the equation of recombination in the following form $(1/N_1 - 1/N_2) = -\alpha\triangle t$ where N_1 is the electron-density at sunset and N_2 is the electron-density after $\triangle t$ seconds. It is doubtful whether it is permissible to apply the equation of recombination for the determination of α in this way. As shown by Langevin[8] α is proportional to the density of the gas. This has been verified experimentally down to a pressure of several cm of mercury. Now the F_2-layer has a considerable vertical extension and the coefficient of recombination decreases from the lower to the upper part of the layer. There is moreover substantial evidence for vertical displacements of the air-masses in the layer at and after sunset. The appearance of the secondary maximum at sunset, which is explained as a contraction of the layer, and the appearance of contraction-layers at heights of 400 to 500 km[1] just after sunset show that the air in and above the F_2-layer contracts when the Sun's rays disappear. The accumulation of charge by contraction will retard the neutralization of the layer; on the other hand the increase in pressure will accelerate the recombination on account of the increase of the coefficient of recombination. In Figures 4, 5, 6, and 7 the part of the electron-density curve after sunset at 250 km has been indicated by heavy lines and the following values of the recombination-coefficient have been computed using the equation of recombination.

TABLE 1

Date	Recombination-coefficient, α
January 6, 1936	5.3×10^{-10}
January 29, 1936	6.2×10^{-10}
March 4, 1936	0.6×10^{-10}
October 10, 1935	1.3×10^{-10}

The recombination-coefficient determined in this way is greater during midwinter than during spring and autumn. This is also evident from the decline of the electron-density curves in Figures 4 and 5 which is more rapid than in Figures 6 and 7. An examination of a number of diurnal curves shows that this increase of the coefficient of recombination is found generally during midwinter. Although the method used for determining the coefficient of recombination can be severely criticized, the more rapid decline of the electron-density curves during midwinter is stated in a number of cases. The most probable explanation for this must be the increase of the pressure in the F_2-layer during the winter which is followed by an increase in the recombination-coefficient. This explanation agrees with the assumption of an annual temperature-variation in the F_2-layer with low temperature and high pressure during winter, which, according to Appleton[9], explains the anomalous annual curve of the noon-values of the critical frequencies for the F_2-layer.

[8]Ann. chim. phys., **28**, 433 (1903).
[9]Nature, **136**, 52-53 (1935).

§3. *Further observations on the posteffects of magnetic storms on the critical frequencies of the F_2-layer and on the curves of equivalent height versus frequency* Besides the momentary formation of new layers at the level of the E-layer during a magnetic storm, and during intense magnetic storms even below this level as an absorbing layer, the magnetic storms also have an indirect effect which is observed in the noon values of the critical frequencies of the F_1- and F_2-layers. Schafer and Goodall[10] have shown that during magnetically disturbed periods the noon values of the critical frequencies of the F_1-layer are reduced. Appleton and Ingram[11] have computed the correlation-coefficient between the critical frequencies of the F_2-layer measured at midnight and the Earth's magnetic activity during the preceding 24 hours and found a negative correlation-coefficient of -0.247. The explanation of this effect is, according to Appleton[9], that during periods of magnetic activity the layer is expanded and the ion-production by the Sun's rays decreases on account of the decrease in pressure. It is of especial interest to ascertain whether this decrease of the critical frequencies is a parallel of a posteffect during magnetically disturbed periods. The critical-frequency determinations at noon in a highly disturbed region like Tromsö are especially suitable for this study. By computing the correlation-coefficient between the critical frequency at noon (or its departure from the smoothed annual curve) and magnetic activity during the following 24 hours, the preceding 24 hours, and the second and third days before the critical-frequency determination, it was shown[5] that the greatest negative correlation-coefficient was obtained between the noon values of the critical frequency and magnetic activity during the preceding 24 hours. This shows that the decrease of the critical frequencies was a posteffect of magnetic storms. This statistical investigation has now been extended, the noon-values of the critical-frequency determination during May 1935 to October 1936 having been used. Table 2 gives the correlation-coefficient between the noon values of the critical frequencies (or the departure of these from the smoothed annual curve) for the F_2-layer and magnetic activity during the following 24 hours (D), during the preceding 24 hours (C) and during the second and third days (B) and (A) before the critical-frequency determination. The greatest negative correlation-coefficient is found between the critical frequency and magnetic activity during the preceding 24 hours (column C).

TABLE 2

Period	A	B	C	D
May-June, 1935	−0.354	−0.517	−0.642	−0.044
July-August, 1935	−0.293	−0.213	−0.427	−0.224
September-October, 1935	−0.020	−0.259	−0.520	+0.019
November-December, 1935	−0.162	−0.257	−0.337	−0.122
January-February, 1936	−0.125	−0.317	−0.599	−0.266
March-April, 1936	−0.314	−0.387	−0.619	−0.355
May-June, 1936	−0.387	−0.555	−0.707	−0.437
July-August, 1936	−0.212	−0.253	−0.450	−0.213

[10] Proc. Inst. Radio Eng., **23**, 670-681 (1935).

[11] Nature, **136**, 548-549 (1935).

There seems to be also a systematic difference between the correlation-coefficients during summer and winter. During summer the effect of magnetic disturbances is traced over a longer period than during the winter.

Besides the reduction in the critical frequencies of the F_2-layer during and after a magnetic storm, the character of the curves of equivalent height (P') versus frequency (f) changes. In Figures 8*A* and 8*B* the equivalent (or virtual) heights of the points of reflection as a function of the frequency are given for a magnetically undisturbed afternoon and for the afternoon of the following day. The curve for the latter day, besides a reduction in the critical frequencies, shows a considerable increase of the equivalent heights and the F_1-maximum is strongly developed, indicating that the gradient of the electron-density has changed. It is easy to show that whereas on May 15, 1936, the F_1-layer must be regarded as a *ledge* in the ionization-curve of the F-layer, there is on June 16, 1936, a *stratification* between the F_1- and F_2-layers. The F_1-layer is evidently less influenced by the magnetic storm, whereas the F_2-layer is expanded. The expansion of the F_2-layer deepens the F_1-ledge to a stratification between the two layers (see Fig. 9).

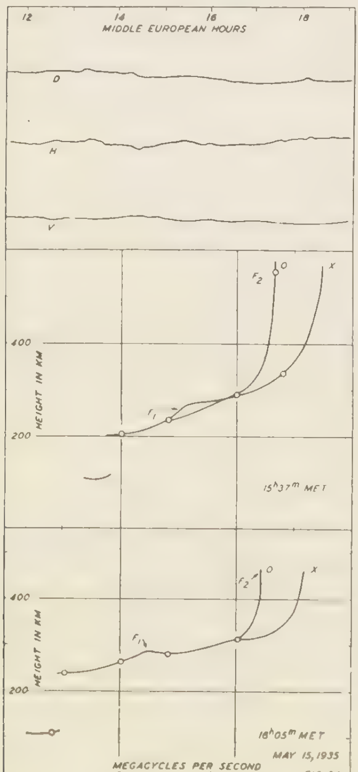


FIG. 8A

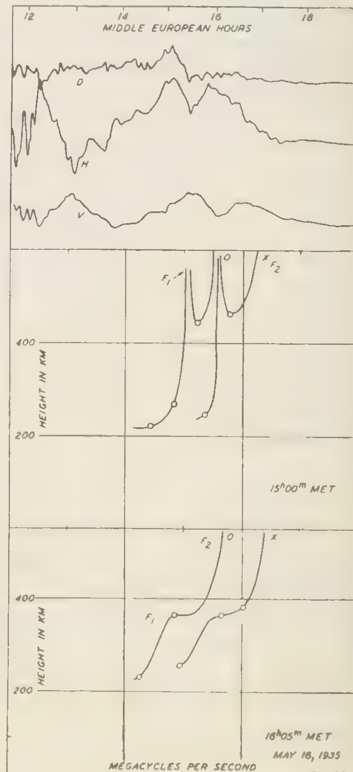
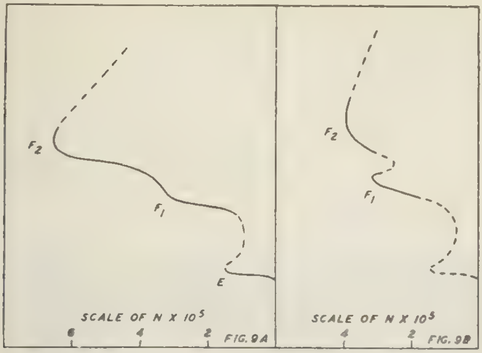


FIG. 8B

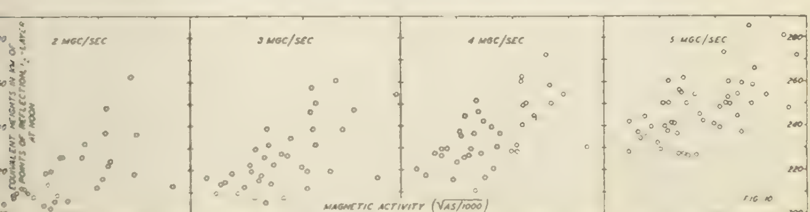


The change of the character of the curve of virtual height versus frequency during disturbed periods is only noticed during strong magnetic storms. But even small storms have an influence on the heights of the points of reflection, without altering the shape of the curve, thus indicating that the gradient of the electron-density has not been appreciably changed.

During midwinter, December to January, the curve of P' and f at noon is especially simple as any traces of the F_1-layer have disappeared. From the noon-records the equivalent heights of the points of reflection in the F_2-layer have been measured for 2, 3, 4, and 5 mgc/sec. The inaccuracy in the height-determination is one to two per cent, corresponding to three to five km in the height of F_2. Figure 10 shows the equivalent heights as a function of the Earth's magnetic activity during each 24 hours, taken out quantitatively from the Observatory's records.

The increase of heights of the points of reflection with increasing magnetic activity is evident on all frequencies. For the highest frequency, five mgc/sec, the influence of the increasing group-retardation when approaching the critical frequency may in some cases have some influence—the mean values of the critical frequencies during December to January were 7.00 and 7.78 mgc/sec (see Table 3). But for the lower frequencies this should be out of question.

§4. *The diurnal asymmetry in the development of the F_1-layer*.—The F_1-layer is in high latitudes, as at Tromsö, developed only during the four summer months. Critical-frequency determination taken regularly at 10^h, 12^h, and 14^h local time show that during normal conditions the F_1-maximum in the curves of P' and f is more predominant before than



after noon. Figures 11*A* and 11*B* show the records and the resulting curves of P' and f. This asymmetry is also generally noticed when determining the critical frequencies at short intervals during 24 or 36 hours continuously for the purpose of constructing the diurnal electron-density curves.

In the vertical distribution of the electron-density, this signifies that the F_1-ledge is more fully developed before noon than after noon; in the course of the day the more or less pronounced stratification between the F_1- and F_2-layers is filled out.

FIG. 11A

§5. *Variations of the coefficient of reflection of the layers during magnetically disturbed periods* Considerable work has been done on the connection between the variations in signal-strength on different wave-lengths and magnetic or solar activity. The series of observations show a correlation between the activity and the signal-strength which may be positive or negative depending on the wave-length[12]. Reflection-coeffi-

[12]See the summary by A. E. Kennelly, Scientific Monthly, 25, 42-56 (1932).

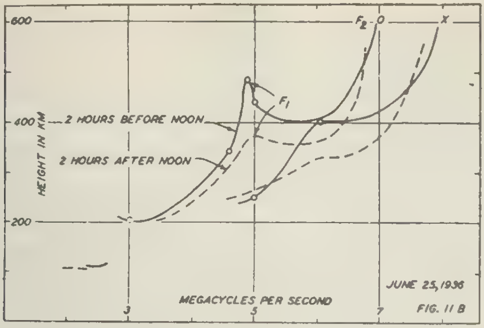


FIG. 11 B

cient measurements over a greater frequency-range by means of radio echoes is a complicated procedure as one has to use a calibrated transmitter and receiver; one has further to separate the echo-components of different polarization and measure each separately[13]. Qualitative estimates of variations of the reflection-coefficient of the layers from day to day can easily be made by estimating the intensity and the number of the multiple reflections recorded. Figure 12 shows the reflection-coefficient estimated from the noon records for the period October to November 1935 as a function of magnetic activity during the same say as determined from the Observatory's records. The diurnal sum (AS) of the hourly departures from the undisturbed values of the horizontal intensity tabulated in the Observatory's yearbook is used as a measure for the activity.

A discussion of the connection between the coefficient of reflection and magnetic activity based on one year's registrations shows the same dependence as illustrated in Figure 12. An inspection of the records

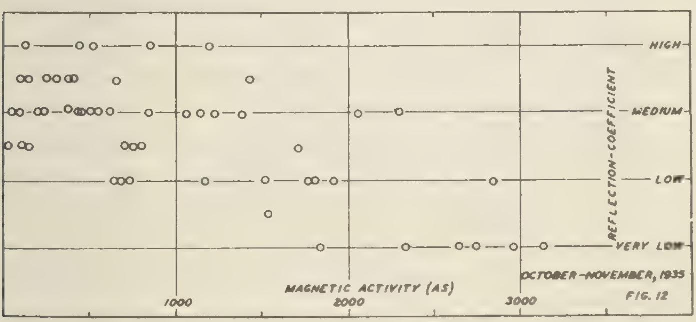


FIG. 12

shows that the decrease in signal-intensity during disturbed periods is most pronounced on the lower frequencies one to three mgc/sec and that on the records during disturbed periods at noon one usually obtains only the echoes from the F-layer. The decrease in the reflection-coefficient

[13]F. W. G. White and L. W. Brown, Proc. R. Soc., 153, 639-660 (1936).

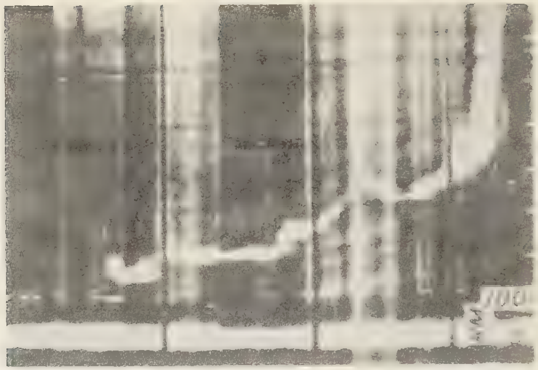
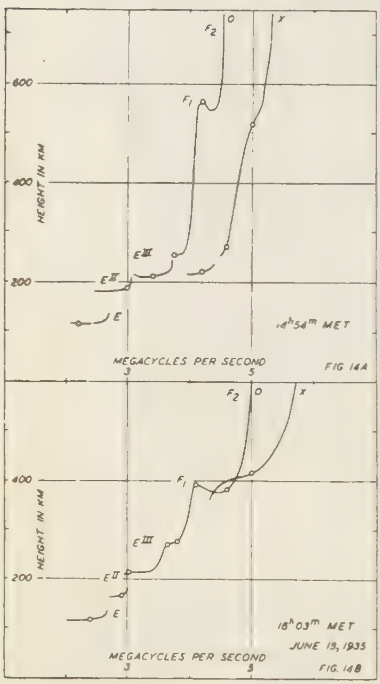


FIG. 13

during disturbed periods must be ascribed to the effect of the absorbing layer below the usual E-layer.

§6. *Occurrence of intermediate layers and reflections between the layers*—Besides the regularly occurring E-, F_1- and F_2-layers, a layer appearing as a stratification or as an intermediate layer between the E- and F_1-layers has been recorded[14]. This intermediate or E^{II}-layer is often recorded in the morning or before noon. Besides this E^{II}-layer we have observed on several occasions that the space between the E- and F_1-layers shows a further stratification. Figure 13 shows a record and Figures 14A and 14B show the resulting curves of P' and f. Besides the E- and F_1-layers there is a stratification at the lower edge of the F_1-layer. This new stratification seldom occurs and has been observed only during midsummer.



Reflections between the layers have previously been observed. J. A. Ratcliffe and E. L. C. White[15] recorded echoes which must be explained as a reflection between the E- and F-layers. These M-echoes have been recorded in Tromsö on a number of days when the E-layer occurred with *abnormally* high critical frequencies up to five to six mgc/sec. Besides the M-echoes previously observed, another combina-

[14] J. P. Schafer and W. M. Goodall, Nature, 131, 804 (1933); E. V. Appleton, Nature, 131, 872-873 (1933).

[15] Phil. Mag., 16, 125-144 (1933).

tion of reflections between the layers was noted. Figure 15*A* shows a record and Figure 15*B* shows the resulting curves for P' and f with the identification of the different combinations of the echoes.

FIG. 15A

§7. *The annual variation of the critical frequencies of the layers observed at noon in 1935 and 1936*—Table 3 summarizes the seasonal variations of the critical frequencies of the E-, F_1-, and F_2-layers during April 1935 to September 1936. Usually the critical frequencies were determined on six days during the week at 10^h, 12^h, and 14^h local time. As previously mentioned the records during magnetically disturbed periods often showed no echoes. In Figure 16 each individual value during the period April 1935 to November 1936 is indicated.

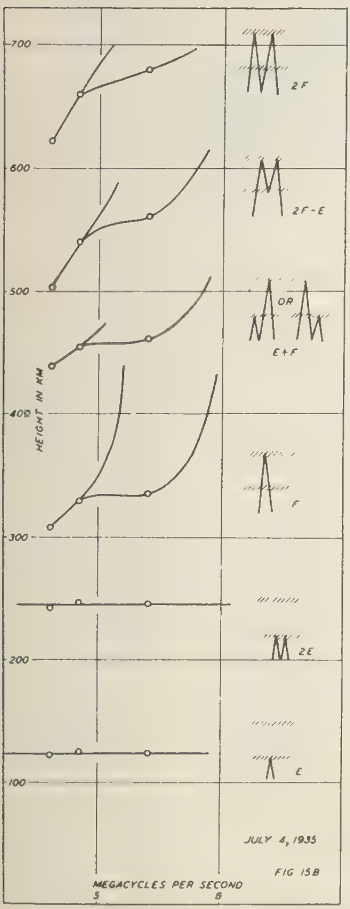


FIG 15B

The F_1-layer is traced in the records only during the four summer months. In midwinter when the Sun is below the horizon, we have not recorded the *normal* E-layer during undisturbed conditions. The variaations of the critical frequencies for the E- and F_1-layers show a variation symmetrical to solstice in accordance with earlier series of observations[16]. Compared with 1935, the values of the critical frequencies during 1936 for E as well as for F_1 show a considerable increase.

The annual variation of the critical frequencies for the F_2-layer shows a more irregular course. The critical frequencies are low in summer and increase during the autumn. There seems to be a secondary minimum about midwinter. In the months of February and March 1936, the critical frequencies again attain high values. Compared with 1935 the critical frequencies for the F_2-layer in the spring of 1936 also show a considerable increase. The mean critical frequency in April and May 1935 was 5.3 mgc/sec compared with 7.3 mgc/sec in 1936. This means that the maximum electron-density has increased from 5.2×10^5 to 9.9×10^5 electrons/cc.

[16]E. V. Appleton and R. Naismith, Proc. R. Soc., **137**, 36-54 (1932). Proc. R. Soc., **150**, 685-708 (1935). S. S. Kirby, L. V. Berkner, and D. M. Stuart, Bur. Stan. J. Res., **12**, 15-51 (1934). J. P. Schafer and W. M. Goodall, Proc. Inst. Radio Eng., **23**, 670-681 (1935).

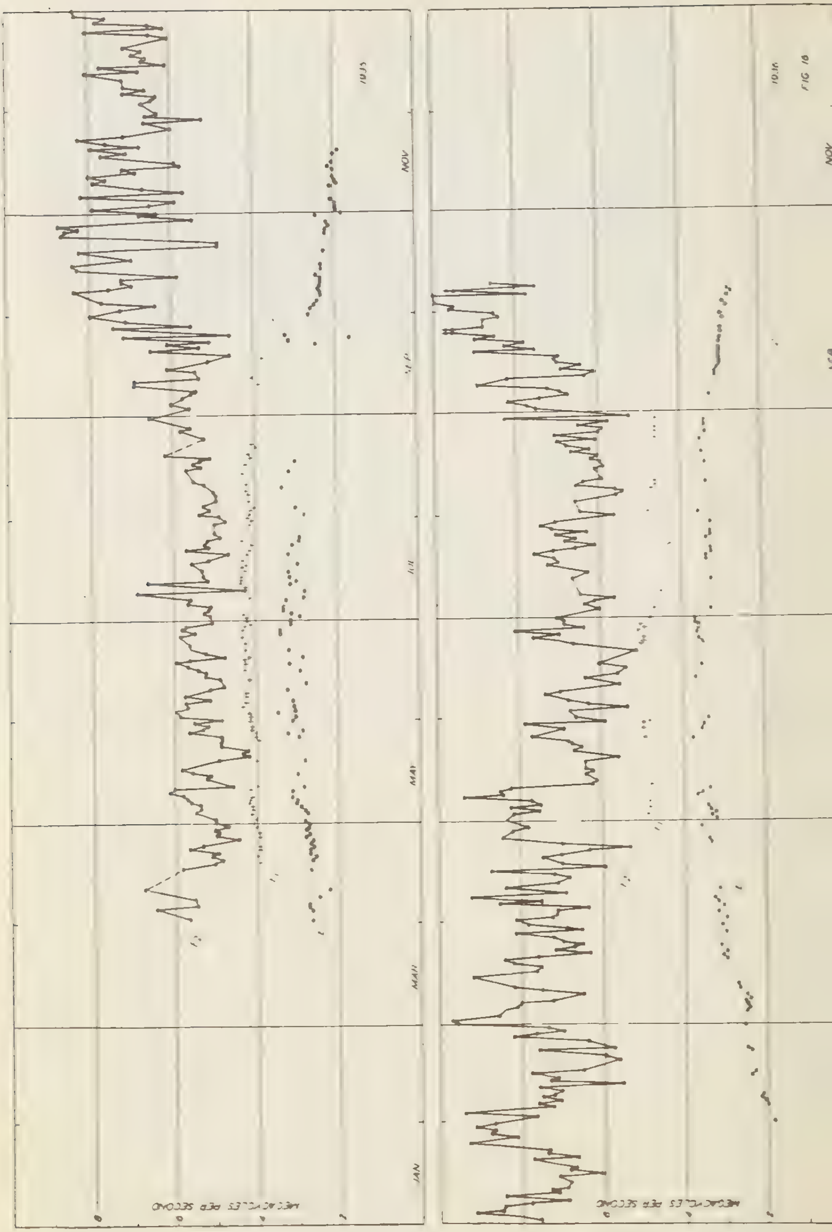


TABLE 3—*Monthly mean values of critical frequencies in megacycles per second, ordinary component only, Tromsö (latitude = 69°.66 north, longitude = 18°.95 east), April 1935 to September 1936*

Region		*E*			F_1			F_2	
Local time	10^h	12^h	14^h	10^h	12^h	14^h	10^h	12^h	14^h
1935 April		2.63			(3.94)			5.30	
May	2.88	2.95	2.88	4.04	4.06	4.02	5.22	5.31	5.06
June	2.98	3.17	2.95	4.22	4.23	4.20	5.51	5.48	5.31
July	2.99	3.09	2.91	4.18	4.20	4.17	5.34	5.25	5.19
August	2.96	3.05	3.01	4.10	4.12	4.08	5.38	5.48	5.29
September	(2.40)	2.79	(2.64)		(3.91)		6.00	6.11	5.79
October	2.25	2.29	2.14				6.63	7.51	6.62
November	1.88	1.98	1.90				5.77	6.90	6.29
December	....	....	....				4.66	7.00	5.59
1936 January	....	....	....				5.78	7.78	7.09
February	(2.02)	2.48	(2.22)				6.64	7.40	7.37
March	2.54	2.75	2.58				7.21	7.73	7.87
April	3.21	3.25	3.21				7.30	7.40	7.29
May	3.36	3.43	3.35	4.80	4.89	4.80	7.32	7.19	6.96
June	3.49	3.61	3.47	4.87	4.96	4.90	6.61	6.61	6.51
July	3.40	3.40	3.40	4.60	4.60	4.60	6.16	6.46	5.97
August	3.23	3.30	3.24		(4.60)		6.84	6.66	6.83
September	2.93	3.01	2.84				7.50	7.85	8.05

As previously mentioned the inverse annual variation of the critical frequencies of the F_2-layer has been explained by assuming an annual variation of temperature and pressure in and above the layer.[7] In a recent paper Berkner, Wells, and Seaton[17] give the results of a series of critical-frequency determinations from Watheroo (Australia) and compare these with the simultaneous records from Huancayo (Peru) and Washington, D. C. According to the "heating" hypothesis one should expect in the Southern Hemisphere an inverse annual variation of the critical frequencies as compared with those observed in the Northern Hemisphere. On the contrary, the data from Watheroo indicate a parallel variation with the observations on the Northern Hemisphere.

The considerable increase in the critical frequencies for all three layers in Tromsö shows that there must be a secular variation in the ion-production in the layers during the past year. It is therefore necessary, as pointed out by Berkner, Wells, and Seaton, to have more extensive series of observations until the question is settled whether the F_2-layer in the Southern Hemisphere shows an inverse annual variation as compared with the Northern Hemisphere. It is to be noted that the series of observations of critical frequencies thus far published commence in 1931 or 1932 and that the period up to 1935 is characterized by low magnetic and solar activities. The increased magnetic activity during the past year may be responsible for the simultaneous increase in the maximum electron-density of all three layers observed in Tromsö and it is probable that this increased activity will have a simultaneous influence on other series of observations.

§8. *The absence of the normal E-layer in midwinter.* As previously mentioned we do not obtain echoes at noon from the normal *E*-layer

[17]Terr. Mag., 41, 173-184 (1936).

during the dark period, November 24 to January 19, when the Sun is below the horizon at Tromsö. It is easy to show that during this period the Sun's rays at noon always reach the atmosphere at a height below the E-layer. On December 23 at noon the height of the Earth's shadow is nine km, but taking the effect of refraction into account, the height is only four km. This means that when the ionizing rays have once passed the E-layer, the ionizing effect when again entering the E-layer from below is zero. This is not the case with the rays which produce the ionization in the F_2-layer; the ionization in the F_2-layer is high during winter even when the Sun's height is negative.

Concerning the nature of the rays producing the ionization in the layers, observations during eclipses[18] indicate that the ionizing agency must be identified with the ultra-violet part of the solar spectrum.

Attributing now the ion-production in the E- and F_2-layers to *two* different parts of the solar spectrum, we find that during midwinter the part of the solar spectrum which is responsible for the ionization in the E-layer is completely absorbed when penetrating the layer, whereas only a fraction of the part of the solar spectrum which produces the ionization in the F_2-layer is absorbed when passing through the layer. This point of view must be assumed if we accept the "heating" hypothesis, which has been offered to explain the inverse annual variation of the critical frequencies of the F_2-layer. Assuming a low temperature and high density in the F_2-layer in winter, it is difficult to understand why this low temperature is restricted to heights above 200 km. The study of the variation of the auroral heights shows that there must be a considerable diurnal temperature-variation at the height of 100 km. It is therefore highly probable that the assumed annual variation of temperature and pressure in the F_2-layer must also be extended to the E-layer. If we now assume a uniform temperature-decrease and a simultaneous increase of pressure in all three layers during winter, we see that this will not affect the ion-production in the E-layer as the ion-production there is fixed by the limited intensity of the part of the solar spectrum which is completely absorbed. For the F_2-layer only a fraction of the ionizing part of the solar spectrum is absorbed; the ion-production there will therefore be mainly determined by the varying masses of air and the maximum electron-density will depend on the pressure. In this way we obtain a simple explanation of the regular annual variation of the critical frequencies for the E-layer and the irregular variations of the critical frequencies for the F_2-layer. For the F_1-layer we associate the ion-production with the complete absorption of a third part of the solar spectrum in the same way as for the E-layer.

[18]See the summary by E. V. Appleton and S. Chapman, Proc. Inst. Radio Eng., 23, 658-669 (1935).

AURORAL OBSERVATORY,
Tromsö, Norway, October 1936

ABNORMAL IONIZATION OF THE *E*-REGION OF THE IONOSPHERE

By L. V. Berkner and H. W. Wells

Abstract—Abnormal ionization of the *E*-region of the ionosphere occurred very infrequently at Huancayo, Peru (12° south, 75° west), during nearly 8000 hours of observation. At Watheroo, Western Australia (30° south, 116° east), the effect was about 70 times as pronounced during the same period. Huancayo is on the geomagnetic equator, while Watheroo is in geomagnetic latitude about 42° south. This evidence suggests that sporadic ionization of the *E*-region is a function of latitude, or more probably of magnetic latitude. It is observed that sporadic ionizations appear most frequently during local summer at stations in the temperate zones. Nevertheless, because of the much greater prevalence of thunderstorms near Huancayo as compared to Watheroo, the suggestion that the effect is related to thunderstorms does not seem to be supported. There is some evidence that the abnormal ionization may be related to magnetic bays and auroras which have a similar distribution with latitude and probably originate largely in the same atmospheric region.

Investigations of ionization of the upper atmosphere during recent years by radio methods have provided a new field of investigation in physics involving the propagation of electromagnetic waves in a doubly-refracting medium of non-uniform density and the production of ions in gas of low density. The dependence of terrestrial-magnetic variations and long-distance radio transmission upon the character of this ionization has insured the rapid progress of investigation which has taken place. With the introduction and improvement of suitable methods of investigation, the conception of the ionized upper atmosphere has progressed from the original rather vague idea to a more comprehensive picture of several major regions, each of which, while merging into adjacent regions, has certain specific characteristics. These characteristics change with location over the surface of the Earth, and it has been necessary to carry on the work at a number of stations which are strategically located. In recent publications by Appleton [see 1 under "References" at the end of paper] and Mitra [2], the progress of these investigations has been comprehensively reviewed in an interesting and effective manner. We are concerned here only with a particular property of the ionized region found at about 100 km which is generally designated as the *E*-region. The data reported herewith from two stations in the Southern Hemisphere add information which must effectively change the background upon which the rather extensive discussion of the phenomenon has been based.

Investigation of this region in the Northern Hemisphere has disclosed the occasional existence of abnormally high values of ion density at heights of 100 to 110 km. These are important because of their predominant effect during periods of occurence. Normally, the ion-density of this *E*-region undergoes relatively smooth diurnal and seasonal variations [3, 4]. It has been demonstrated that this normal ionization is caused principally by electromagnetic radiation [5, 6] from the Sun. This normal maximum of ion-density reaches a value of about 1.8×10^{5}, expressed in equivalent numbers of electrons per cc, when the Sun is directly overhead [7]. A wave of radio frequency 3.8 mc/sec will just penetrate a region of this ion-density at normal incidence.

Occasionally, reflections of great magnitude are observed from the *E*-region when frequencies much higher than the normal critical penetration-frequency for the *E*-region are used [3, 4, 8, 9, 10, 11]. Reflections from the upper regions, otherwise apparent on these frequencies, may be

entirely obscured. It is therefore supposed that an abnormal or "sporadic" ionization must have occurred in the *E*-region. Such events may occur at any hour and last for a few minutes or even several hours. Ion-density during such periods often exceeds 10^6 equivalent electrons per cc, as deduced from the penetration-frequency.

Ionosphere-observation at the Huancayo Magnetic Observatory, Peru, in latitude 12° south and longitude 75° west [12, 13, 14], and at the Watheroo Magnetic Observatory, Western Australia, in latitude 30° south and longitude 116° east [15], by the Department of Terrestrial Magnetism, Carnegie Institution of Washington, permits a further investigation of this effect. It is especially significant that Huancayo Magnetic Observatory is at the geomagnetic equator and that both stations are in the Southern Hemisphere.

The results at these observatories, upon which this paper is based, cover the period July 1, 1935 to May 15, 1936. The frequency of 4.8 mc/sec, used in the study, ordinarily penetrates the *E*-region, but is reflected from this region when the ion-density increases about 50 per cent over the normal maximum. Records at Huancayo are practically continuous for about 7680 hours during the period. Data at Watheroo were taken manually three days a week during such times that the entire 24 hours were canvassed regularly. These observations covered about 1090 hours—one-seventh of the entire period.

Two phenomena, somewhat similar but nevertheless distinct, were observed. The first, represented by the black blocks of Figure 1, was the appearance of strong reflections from the *E*-region, accompanied by one or more multiple reflections, characterized by complete cessation

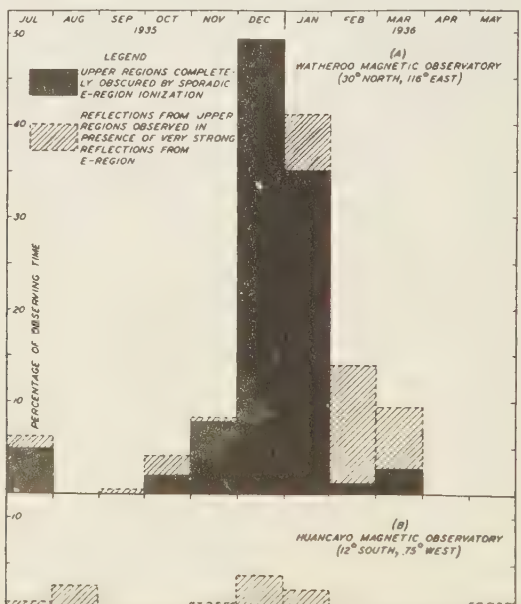


FIG. 1—APPEARANCE OF SPORADIC E-REGION IONIZATION EXPRESSED IN PER CENT OF OBSERVING TIME (OBSERVING FREQUENCY 4.8 MC/SEC)

of reflections from higher regions on the observing frequency. This condition is illustrated by Figure 2. The second, shown by the hatched blocks of Figure 1, was similar except that reflections from the upper regions were observed. This latter effect probably arises from partial reflection from a relatively sharp boundary; it may indicate a change of ion-distribution or ion-gradient [16] but not an increase of equivalent electron-density to 2.8×10^5.

Two factors of particular significance are recognized in Figure 1. While sporadic ionization is not infrequent at Watheroo, it is rarely observed at Huancayo. Furthermore, its occurrence seems definitely related to the December solstice.

Sporadic ionization of the *E*-region at Huancayo was observed only during 6.3 hours of almost a year of continuous observation, while at Watheroo, in only one-seventh of the total observing time (1090 hours), it appeared during about 60 hours. The effect was therefore about 70 times as apparent at Watheroo.

The effect at Huancayo was confined to four days in December and January which corresponds to its most frequent appearance at Watheroo. The Sun is overhead at Hunacayo during October and February; therefore, the effect seems associated with the Sun's declination.

The association of the effect with local summer months caused much conjecture concerning a possible local terrestrial origin. Two mechanisms proposed by C. T. R. Wilson [17] involving the effect of the high electric fields of thunderclouds have been invoked [3, 9]. The first involves the electrical breakdown of the high atmosphere above thunderclouds, Sporadic ionization of the *E*-region from this cause should appear in the vicinity of the thunderstorm area, unless high conductivity of the ionized region disposes of the charge as rapidly as formed. The frequency of thunderstorms is very much greater at Huancayo than at Watheroo. When the relative absence of abnormal ionization at Huancayo is considered, this explanation for the effect seems improbable, in agreement with the conclusion of Healey [18], based on theoretical considerations.

The second involves ionization by beta particles, or "runaway electrons," accelerated in high thunderstorm fields. The electron,

accelerated upward in the high electric field and at Huancayo across the Earth's magnetic field, would move eastward. It might be argued that sporadic *E*-region ionization at Huancayo does not occur because the necessary thunderstorm field must be westward and therefore over the Pacific Ocean where thunderstorm conditions are infrequent. It could be further adduced that, while Watheroo is similarly located near a western coast, the high inclination of the Earth's magnetic field there would not prevent a sporadic ionization from local thunderstorms. Infrequency of thunderstorm fields near Watheroo minimizes this possibility.

The prevalence of sporadic *E*-region ionization in polar regions has been mentioned by Appleton [9] and Fleming [10]. The effect is in evidence in such latitudes even during the winter night. It is difficult to reconcile this fact with the suggested origin of sporadic ionization in thunderstorm fields, in view of the absence of such ionization at Huancayo.

The relative absence of sporadic ionization of the *E*-region at Huancayo is particularly significant. Prevalence of such effects north and south of Huancayo suggests that the phenomenon may depend on latitude or, more probably, on geomagnetic latitude, as well as on solar declination. Other geophysical phenomena such as auroras, and certain types of magnetic disturbances such as bays, which are similarly distributed with respect to latitude, have a seasonal distribution of occurrence, and probably originate in the same atmospheric region. No relation between the sporadic *E*-region ionizations and magnetic disturbances of widespread character is apparent so far at Huancayo and Watheroo. However, magnetic conditions have been relatively undisturbed during this period. It is probable that these effects are related more closely to the relatively frequent and local magnetic disturbances observed only in large magnitude near the polar regions as shown by Harang [19].

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THE MEASUREMENT OF NORMAL ATMOSPHERIC-ELECTRIC POTENTIAL-GRADIENTS USING A VALVE-ELECTROMETER

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Abstract—An account is given of a valve-method for measuring normal atmospheric-electric fields. The apparatus was run for one month in an exposed position subject to all types of bad weather and functioned well throughout. No difficulty at all was experienced with insulation, and the apparatus as used with a string-recorder gave a reliable record of fields up to about 400 volts per meter. By small alterations the range could have been increased or alternatively the apparatus made more sensitive for lower values. Comparisons with a radioactive collector and quadrant-electrometer showed that the valve-apparatus was unaffected by moist conditions which spoiled the insulation of the collector.

Introduction—During 1933 the writer was engaged in making observations on atmospheric-electric potential-gradient from aeroplanes using the test-plate method of C. T. R. Wilson. In order to give a continuous record the test-plate was covered and uncovered by a rotating earthed vane and the resulting alternating current was measured by means of a triode valve. The same principle has been used by various workers to measure very high potentials, and the apparatus worked well in the fields of 1000 volts per meter at the surface of the aeroplane. In a normal field at ground-level there was only a small deflection of the measuring instrument but it seemed likely that with slight amplification the apparatus would give a reliable record of ordinary atmospheric fields. The present account describes the construction and testing of an apparatus which has been found suitable for measuring ordinary atmospheric-electric fields of the order of 0 to 400 volts per meter.

The principle of the apparatus—The essential features of the apparatus are readily seen if we consider a triode valve with a recording instrument in the anode-circuit, the grid being insulated and connected to an insulated plate which can at will be exposed to an electric field or shielded from it by an earthed metal plate moved above it. When the test-plate is shielded the grid and plate will take up a floating potential dependent on the characteristics and insulation of the valve.

If, now, the earthed cover is removed and the test-plate is exposed in a negative field, a positive charge is induced on its upper surface, while the corresponding negative charge is distributed over the grid, the back surface of test-plate, and the leads from test-plate to grid. If the capacity of the leads is small the grid-potential will reach a considerable negative value and the anode-current will be correspondingly reduced. The anode-current will rise comparatively slowly to its undisturbed value as the negative charge on the grid vanishes, partly neutralized by the small positive-ion current and partly by leakage over the insulation. The test-plate will be left with the positive charge bound on its upper surface. When the plate is shielded again this positive charge spreads to the grid but is almost instantly neutralized by the stream of electrons, so that there is only a very small momentary rise in grid-potential and in anode-current. The actual change will vary with the rate of shielding of the test-plate, that is, the rate at which positive charge reaches the grid. If the positive charge can be neutralized as rapidly as it reaches the grid, there is no change in anode-current. This is the case unless the field is very large or the rate of shielding very rapid.

In a positive field a negative charge is induced on the test-plate on exposure and a positive charge sent to the grid. This positive charge is almost immediately neutralized as above and produces only a momentary increase in grid-potential and anode-current. However, on shielding the plate again, the negative charge previously bound on the test-plate spreads to the grid, producing a large decrease in grid-potential and anode-current. This charge slowly disappears from the grid and the anode-current rises to its earlier value.

Thus, in a positive field there is a very small increase in anode-current on exposure of the test-plate and a large decrease on shielding again. In a negative field the large decrease occurs on exposure and small increase on shielding again.

The magnitude of the quantities induced on the test-plate will be the same in equal positive or negative fields, but owing to the proximity of the shielding plate the capacity of the system is greater when shielded. Therefore, in a positive field, where the main deflection occurs on shielding, the deflection is slightly smaller than in a negative field of the same strength where it occurs on exposure.

When the processes of shielding and unshielding the test-plate are carried out in rapid succession, by using a shield rotated on a spindle, then the measuring instrument in the anode-circuit shows a succession of downward kicks in the current. These come closer together as the speed is increased and finally a steady decrease is obtained which depends upon the sign and magnitude of the field and the constants of the measuring instrument.

In normal atmospheric-electric fields the actual changes in anode-current of a single valve were found to be insufficient to allow of accurate measurements on fields of 100 volts per meter or less and hence the fluctuations were amplified, using a second valve with resistance-capacity coupling. This increased the deflections sufficiently to enable a field of 50 volts per meter to be measured within three or four volts.

A second amplifier was also tried, but although this increased the sensitivity greatly, the range was correspondingly reduced and the larger values of atmospheric field frequently encountered could not be measured on the same scale as the lowest values. Consequently, this third valve was dispensed with as an amplifier. It is worth noting that when two amplifiers were used, we could, by putting a small capacity in parallel between the test-plate and the grid of the first valve, reduce the deflection obtained for a given field by a definite factor and hence extend the scale. It might be desirable in some cases to use the additional valve and plug in the capacity across the first grid when the field rose. In the present case it was better to use only the single amplifier.

In order, however, to eliminate the effect of battery fluctuations and to have a zero-current in the recording instrument in zero-field, a third valve was arranged in a balanced bridge-circuit with the second valve and the recorder put across the two arms. The arrangement is shown in Figure 1.

The actual apparatus—The valves found most satisfactory were Osram LP2 and Mullard PM2A. In the final arrangement valve 1 was a Mullard and valves 2 and 3 consisted of a pair of carefully matched Osrams, all run with an anode-potential of 68 volts. The values of the other components were: Capacity, $C=0.001$ μF; resistances R 10,000

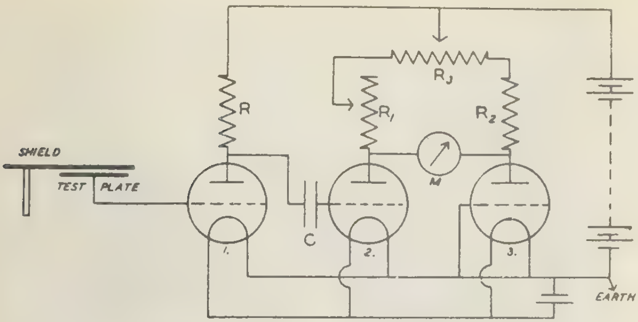


FIG. 1

ohms; R_2, 400 ohms; R_1, a rheostat of 500 ohms; and R_3 a 50-ohm potentiometer. The contacts on resistances R_1 and R_3 were adjusted so that zero-current flowed in the microammeter when the test-plate was shielded, and this adjustment, once made, remained sensibly constant. To increase its insulation the ebonite was cut away around the grid-contact of the first valve.

The apparatus was fitted inside a rectangular aluminum box 10 inches by 14 inches and 15 inches deep, except for the batteries, recording instrument, and switches which were in a small wooden shelter, the two being joined by a 25-foot length of multistranded cable. The aluminum box consited of two portions. The lower and larger was merely a cover while all the apparatus was mounted on the upper which fitted as a lid down onto the lower.

Figure 2 shows the arrangement in the aluminum box diagrammatically and Figures 3 and 4 are photographs of the actual box. The line *AB* in Figure 2 indicates an aluminum casting which bears all the

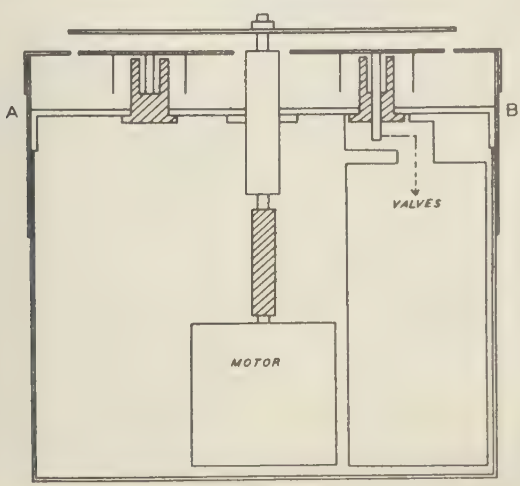


FIG. 2

weight and is rigidly riveted to the outer casing of the box. It is ridge-shaped at top allowing any rain which may enter to run off through holes at the edge. The insulators for the test-plate and the axle for the rotating shield pass through the ridge of the casting, the junctions being made water-tight so that all of the apparatus contained below is completely protected from the weather.

The rotating shield is mounted on the axle shown and is driven by a 6-volt motor contained in a metal box supported on a bracket beneath the aluminum casting. This box was insulated, not earthed, as it was found that earthing the box or any part of the motor-circuit caused disturbance in the valve-circuits. A 3-inch length of pressure-tubing coupled the motor to the bottom of the axle.

The test-plate in the shape of two opposite quadrants of a circle (radius 11 cm) rigidly joined by a metal tube is fitted into the two insulators of ebonite and sulphur by plug-and-socket fixtures and thus can at any time be readily removed for examination of the insulators. When fitted, it is flush with the top of the box, the loose lid of which (shown in Fig. 3) was cut away to give 5-mm clearance all round the test-plate.

Figure 3 shows the top of the box with the lid and the test-plate dismounted and the rotating shield entirely removed. In Figure 4 the top is shown with all parts fitted, while alongside is the switchboard from which everything was controlled and which was mounted in the second box at a distance.

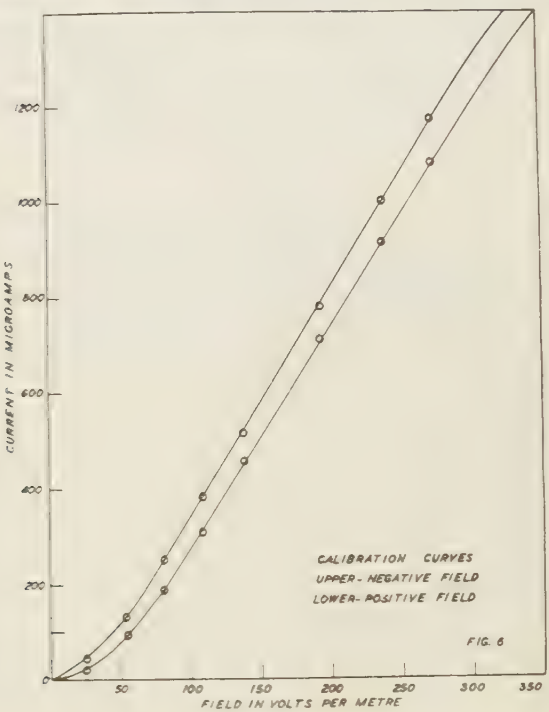
The valves were mounted in a metal box also supported below the aluminum casting and so arranged that the lead passing from the test-plate down through one insulator to the first valve was as short and of as small capacity as possible. Each valve was in a separate compartment and mounted on rubber sponge.

The joint between the lower portion of the main box and its "lid" was sealed with plasticene so that the enclosed apparatus was entirely weather-proof and the box was sunk in the ground until the test-plate was level with the surface, a square iron sheet with opening for the box being laid on the ground. A 25-foot length of multistranded cable led from the box to the small shelter in which the batteries, recorders, and switchboard, with the adjustable resistances R_1, R_2, and R_3, were kept. This arrangement was convenient, for when once the apparatus was working, any adjustment was made at the one position without approaching or moving the main apparatus. The measuring instrument used was a Cambridge string-recorder giving a record every minute with a full scale-deflection for 750 microamperes. It was used shunted to read up to 2000 microamperes.

The arrangement when set up on Signal Hill, Dunedin, and when a calibration was in progress, is shown in Figure 5.

Calibration The method of calibration is extremely simple. A parallel plate was mounted 25 cm above the test-plate as shown and the reading of the recorder was noted when known potentials were put on this upper plate. Calibration-curves obtained with the apparatus are shown in Figure 6. The curve for negative fields is slightly above that for positive fields for the reason explained earlier. When the apparatus was recording on Signal Hill, calibration-marks for several field-values were put at the end of the old chart and at the beginning of the new, when the charts were changed each day. Such marks are seen on Figures 8 to 12


FIG. 5


CURRENT IN MICROAMPS
FIELD IN VOLTS PER METRE
CALIBRATION CURVES
UPPER - NEGATIVE FIELD
LOWER - POSITIVE FIELD
FIG. 6
0
200
400
600
800
1000
1200
50
100
150
200
250
300
350

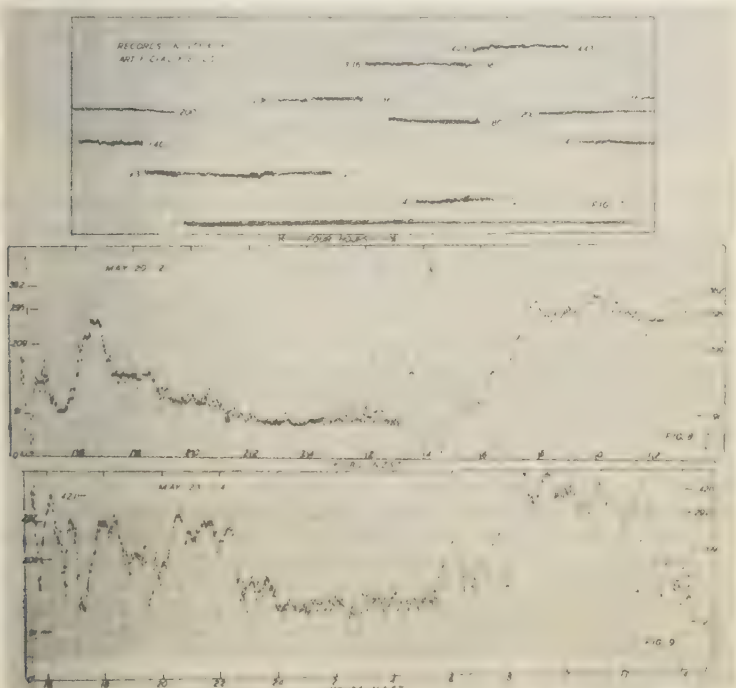
To test the constancy of reading, the apparatus was run continuously in steady fields for periods of several days. Figure 7 is a copy of records covering 48 hours and shows the degree of steadiness of the reading in a fixed field. The slight fall in the reading for 200 v m was due to discharge of the batteries. When the batteries were kept steady no appreciable variation occurred.

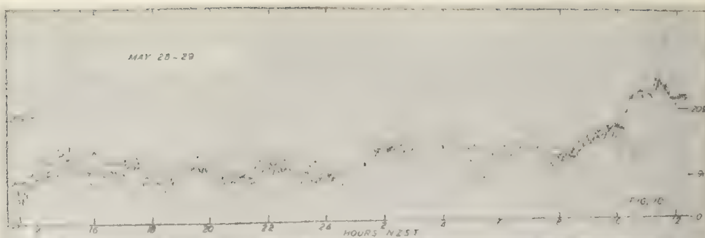
Site—The apparatus was set up on a flattened spur of Signal Hill some two and a half miles north from the center of Dunedin and at an altitude of 750 feet. The site was chosen as being well removed from the city smoke on a comparatively level stretch of ground with no obstructions near and yet only two hundred yards from a farm road. Accessibility by car was desirable as the batteries for driving the motor and also supplying the filament-current to the valves had to be changed daily. The nearest house was an isolated one over 400 yards away and lower than the site.

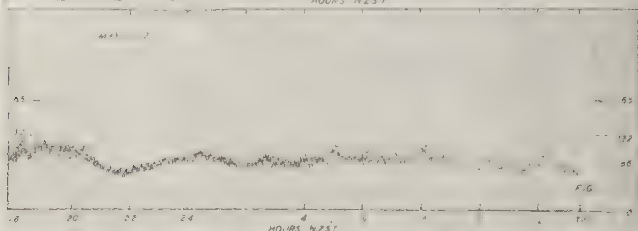
The surrounding topography is very broken, but application of the results of Allen[1] and of Lees[2] indicated that any electric fields observed at the site should be reduced by 20 per cent to give the equivalent field on a plane surface.

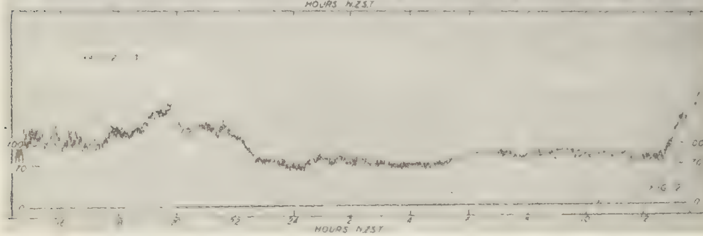
Records obtained—It was hoped to keep the apparatus going for a

[1]Canberra Mem. Solar Obs., 1, No. 4 (1934).
[2]Proc. R. Soc., 91, 440-451 (1915).









ısiderable time and so obtain some information about the variations the gradient at Dunedin. However, the author received notice of nsfer away from Dunedin just when the apparatus was set up. As a ult records were obtained for one month only.

During this period the apparatus ran continuously except for the ly stoppage when the batteries were changed. During the month types of weather were experienced, including rain, hail, and snow, and throughout the apparatus functioned without any trouble. Each day before and after the batteries were changed the apparatus was calibrated. These tests proved that so long as the batteries remained fully charged the calibration was constant. If the power required could be obtained from a town supply then the recorder would run for a considerable period without any noticeable variation in calibration.

Copies of typical records obtained are shown in Figures 8 to 10. The times given are all local mean time. The record of Figure 8 was taken with a southwesterly wind and a changeable sky with two showers, one at the beginning of the record, and a second between 4^h and 5^h. The decrease in the field after 17^h in the evening and increase again between 6^h and 8^h in the morning was typical of several records obtained with a southwesterly wind which would blow from over the city and presumably bring smoke and other pollution over the site during the day.

Figure 9 was also taken in a southerly wind with misty rain up till

midnight and then a gradual improvement during the night and following forenoon.

Figure 10 is a record obtained on a day with a northerly wind when a thick wet mist enveloped the instrument throughout.

Diurnal variation—The weather was cloudly with considerable low cloud during most of the period, but for two days, May 11 and 12, the sky was clear with a strong northerly wind of gale force much of the time. The records obtained on these days are shown in Figures 11 and 12, and the hourly values for the two days, reduced by 20 per cent to correct for the site, are plotted in Figure 13. The curves cannot be taken as giving accurate average values for the locality but they do, perhaps, give some indication of the nature of the diurnal variation.

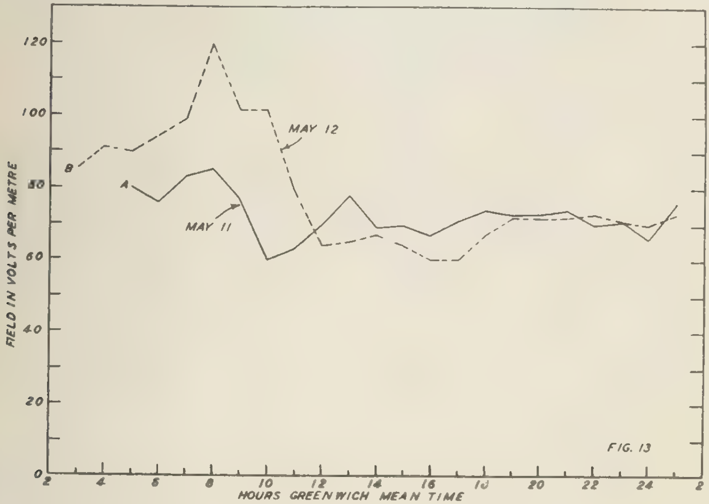


FIG. 13

The features in which they agree are a maximum at about 7^h to 8^h GMT followed by a rapid fall, then a small rise and fall again to a minimum at 16^h in each case, then another rise to a rel tively flat maximum from 19^h to 21^h. It is possible that this latter maximum bears some relation to the universal maximum at about this hour. Further observations would be necessary to determine the reality of the maximum at 8^h GMT. Such a maximum is of course, a feature of records from many stations on land such as Kew where it has been shown to be connected with increase in local atmospheric pollution. In the present case, however, there is every reason to suppose that such an explanation is not likely as the wind passed entirely over sparsely settled land before reaching the site and any pollution from Dunedin would have been blown in the opposite direction.

Comparisons with a radioactive collector—The apparatus was compared with a radioactive collector attached to a quadrant-electrometer by setting both up on the roof of the Physics Building and taking simul-

taneous readings. Owing to the proximity of ventilators, chimneys, etc., it was not to be expected that the two would give the same absolute value and so the ratio of the two was compared.

The results showed that the valve-apparatus followed changes in field more rapidly than the radioactive collector and that the ratio remained constant so long as everything was dry, but even though the quartz-insulators of the radioactive collector were shielded and as clean as possible, whenever mist appeared in the evening the field recorded by the radioactive collector fell slowly while no alteration was noticeable in the valve-apparatus. In every case this was traced to the insulation of the radioactive collector. Although the insulation of a permanent radioactive collector could undoubtedly be made better than in this case, insulation-troubles are a well-known source of error with such apparatus and the comparative independence of the valve-apparatus on the small leaks which so adversely affect radioactive-collector measurements is a great advantage of the valve-method.

Another advantage is that the plates can be set on the ground and there is no disturbance of the electrical state as when a radioactive collector is introduced.

The major disadvantage is that separate tests of shielding and unshielding are necessary to determine with which deflection occurs and so show whether the field is positive or negative. This test is quickly made but nevertheless on a disturbed day where the field changes sign frequently it is difficult to determine the sign unless an observer remains with the instrument. As, however, in all measurements to determine diurnal variation only quiet days are used, this disadvantage is of little importance. For instance, on May 10 and 11 the field was found to be positive throughout.

If necessary, a subsidiary radioactive collector might be used to give the sign, in this case small leaks being immaterial as the value would be found from the valve-recorder.

The work on this apparatus was begun at the Solar Physics Observatory, Cambridge, England, and continued at the University of Otago, Dunedin, New Zealand. It is a pleasure to express my thanks to Professors Stratton of Cambridge and Jack of Dunedin for the use of their laboratories. In Dunedin in particular, I had considerable assistance at different times from E. P. Blampied and A. K. Holt in testing the apparatus and maintaining it on Signal Hill.

Meteorological Office,
Wellington, New Zealand

LETTERS TO EDITOR

PROVISIONAL SUNSPOT-NUMBERS FOR DECEMBER, 1936, AND JANUARY AND FEBRUARY, 1937

(Dependent alone on observation at Zürich Observatory and its station at Arosa)

Day	December	January	February
1	193[bdd]	145	211[a]
2	...[b]	163[a]	224
3	...[a]	109[a]	181[a]
4	...	*M*112[c]	*E*152[c]
5	158	...[a]	146[a]
6	*E*146[c]	*ME*82[cc]	*W*...[c]
7	...[aa]	94	98
8	*E*134[c]	...	*E*90[c]
9	104	97	*E*76[c]
10	107[a]	*M*85[cd]	...
11	82[d]	97[d]	...[a]
12	*W*76[c]	91	*M*77[acd]
13	74[d]	*W*80[c]	...
14	71	91	89
15	40	...	79
16	43	*M*108[ac]	101[d]
17	*W*70[ac]	*E*108[acd]	92
18	88[d]	112	88[ad]
19	85[a]	...	97[d]
20	74	*E*128[c]	100[d]
21	86[dd]	*WEE*127[ccc]	130[a]
22	117	163	167[add]
23	130	155	155[a]
24	*E*149[accd]	178[abdd]	164[ad]
25	151	*M*181[ac]	164[aa]
26	150[a]	*E*200[bcd]	*E*167[ac]
27	161[a]	*E*180[c]	149
28	135[ad]	210	*W*...[ac]
29	*E*167[acd]	*M*...[cd]	
30	*E*200[ac]	233[ab]	
31	181	233[ab]	
Means..	117.5	137.0	130.3
No. days	27	26	23

Mean for quarter October to December, 1936: 105.3 (79 days)
Mean for year 1936: 78.2 (336 days)

[a]Passage of an average-sized group through the central meridian.
[b]Passage of a large group or spot through the central meridian.
[c]New formation of a group developing into a middle-sized or large center of activity: *E*, on the eastern part of the Sun's disc; *W*, on the western part; *M*, in the central-circle zone.
[d]Entrance of a large or average-sized center of activity on the east limb.

EIDGEN. STERNWARTE,
Zürich, Switzerland

W. BRUNNER

AVERAGES OF CRITICAL FREQUENCIES AND VIRTUAL HEIGHTS OF THE IONOSPHERE, OBSERVED BY THE NATIONAL BUREAU OF STANDARDS, WASHINGTON, D. C., FOR JANUARY AND FEBRUARY, 1937[1]

The following ionosphere data are in continuation of those published for 1934-36 in this Journal[2]. The symbols used are:

h_E = E-region virtual height, kilometers (lowest measured height)
h_{F_1} = F_1-region virtual height, kilometers (lowest measured height)
h_{F_2} = F_2-region virtual height, kilometers (lowest measured height)
f_E = E-region critical frequency, kilocycles per second, ordinary ray
$f^o_{F_1}$ = F_1-region critical frequency, kilocycles per second, ordinary ray
$f^x_{F_2}$ = F_2-region critical frequency, kilocycles per second, extraordinary ray
EST = Eastern Standard Time (75° West Meridian Time); add 5 hours for Greenwich time
= Manual measurements
* = Less than ten measurements with automatic recorder

[1]Communicated by the director of the National Bureau of Standards of the United States Department of Commerce.
[2]T. R. Gilliland, S. S. Kirby, N. Smith, and S. E. Reymer, Terr. Mag., **41**, 379-388 (1936).

Table 1—*Ionosphere data, National Bureau of Standards, Washington, D. C.*

EST	h_E	h_{F_1}	h_{F_2}	f_E	$f^o_{F_1}$	$f^x_{F_2}$	h_E	h_{F_1}	h_{F_2}	f_E	$f^o_{F_1}$
			January, 1937[a]						*February, 1937*[a]		
00			300			5060			284		
01			317			5105			293		
02			301			5173			295		
03			294			5095			294		
04			290			4847			297		
05			299			4550			294		
06	.		300	800#		4468	...		287	1000#	
07	...		279	1250#		5550	...		249	1880#	
08	...		229	2287		8310#	...		236	2552	
09	127		234	2865		9600#	127		233	3031	
10	122		232	3225		11400#	124		230	3386	
11	119		233	3450		12220#	122		232	3618	
12	121		233	3532		11920#	125		234	3772	
13	120		231	3472		11750#	122		237	3738	
14	122		232	3297		11780#	122		237	3551	
15	124		239	3010		11800#	123		238	3271	
16	127		239	2558		11420#	125		242	2898	
17	...		234	1910#		11000#	...		240	2346	
18			239			10020#	...		235	1580#	
19			238			8470#			239		
20			249			7050			245		
21			270			5980			258		
22			286			5560			271		
23			298			5360			280		

[a]No F-layer stratification in evidence during January and February.

National Bureau of Standards,
United States Department of Commerce,
Washington, D. C.

AMERICAN *URSI* BROADCASTS OF COSMIC DATA[1] OCTOBER TO DECEMBER, 1936

The data for terrestrial magnetism, sunspots, and solar constant are the same as given in previous tables.

The first three columns of the Table give (1) the magnetic character according to the scale 0-2 of the International Commission of Terrestrial Magnetism and Atmospheric Electricty, (2) the type featuring the day other than normal by the letters *b*, *p*, *o*, and *i* for days marked by bay, rapid pulsations, long-period oscillations, and irregular oscillations, respectively, and (3) the hour and minute of Greenwich mean time marking the beginning of a storm, the end of the storm being indicated in the footnote to the Table. The next two columns give the data relating to sun-

[1]For previous announcements see Terr. Mag., **35**, 184-185 and 252-253 (1930); **36**, 54, 141, 258-259, and 358-360 (1931); **37**, 85-89, 189-192, 408-411, and 484-487 (1932); **38**, 60-63, 148-151, 262-265, 335-339 (1933); **39**, 73-77, 159-163, 244-247, 353-356 (1934); **40**, 111-115, 220-222, 334-336, 449-452 (1935); **41**, 85-87, 207-209, 315-317, 407-409 (1936).

Summory American URSI daily broadcasts of cosmic data, October to December, 1936

October							November							December							Date
Magnetism			Sun-spot		Solar constant		Magnetism			Sun-spot		Solar constant		Magnetism			Sun-spot		Solar constant		
Character	Type	G. M. T. begin. distur.	Groups	Number	Value	Character	Character	Type	G. M. T. begin. distur.	Groups	Number	Value	Character	Character	Type	G. M. T. begin. distur.	Groups	Number	Value	Character	
		h m			*cal*				*h m*			*cal*				*h m*			*cal*		
0	...	.. ..	12	85	1.946	*s*	0	...	.. ..	...	...	1.941	*s*	0	...	.. ..	14	140	1.952	*f*	1
0	...	.. ..	...	...	1.940	*s*	0	...	.. ..	9	105	1.946	*f*	0	...	.. ..	13	165	1.955	*u*	2
0	...	.. ..	8	150	1.940	*s*	1	*i*	3 45	10	50	1.954	*f*	0	...	.. ..	...	...	......	...	3
0	...	.. ..	11	110	1.943	*s*	1	...	.. ..	11	85	1.946	*s*	0	...	.. ..	...	...	......	...	4
0	...	.. ..	11	140	......	...	1	...	.. ..	12	50	1.944	*s*	0	...	.. ..	13	95	......	...	5
1	...	.. ..	9	120	......	...	0	...	.. ..	14	145	1.951	*s*	0	...	.. ..	13	105	......	...	6
1	*b*	8 00	10	125	......	...	0	*b*	16 15	12	85	1.948	*s*	0	...	.. ..	10	60	......	...	7
1	...	.. ..	11	100	......	...	0	...	.. ..	12	25	......	...	0	...	.. ..	13	105	1.933	*f*	8
0	...	.. ..	11	105	......	...	1	...	.. ..	13	85	......	...	0	...	.. ..	11	90	......	...	9
1	*i*	1 00	8	50	1.940	*f*	0	...	.. ..	15	80	......	...	0	...	.. ..	9	70	1.935	*f*	10
0	...	.. ..	9	40	1.942	*s*	0	*b*	6 00	11	95	......	...	0	...	.. ..	11	65	1.937	*f*	11
0	...	.. ..	9	40	1.946	*s*	1	...	.. ..	12	125	......	...	0	...	.. ..	7	45	1.934	*f*	12
0	...	.. ..	8	40	......	...	0	...	.. ..	11	100	1.944	*f*	0	...	.. ..	...	...	1.935	*f*	13
0	...	.. ..	9	85	......	...	0	...	.. ..	9	80	1.948	*f*	0	...	.. ..	...	...	1.936	*f*	14
1	*b*	2 25	8	95	......	...	0	...	.. ..	8	70	1.954	*f*	0	...	.. ..	...	...	1.935	*s*	15
1	...	.. ..	...	...	1.941	*s*	1	...	.. ..	9	60	1.942	*s*	0	...	.. ..	...	...	......	...	16
1	*i*	15 00	...	...	1.953	*f*	1	*p*	.. ..	8	35	1.945	*s*	0	...	.. ..	3	50	......	...	17
0	...	.. ..	...	...	1.948	*f*	1	*i*	.. ..	7	30	1.951	*f*	0	...	.. ..	6	45	......	...	18
0	...	.. ..	...	...	1.946	*f*	1	...	.. ..	4	25	1.951	*s*	0	...	.. ..	...	...	......	...	19
0	...	.. ..	6	50	1.942	*f*	0	...	.. ..	2	25	......	...	0	...	.. ..	8	90	......	...	20
0	...	.. ..	7	35	1.949	*f*	0	...	.. ..	1	25	1.953	*u*	0	...	.. ..	10	95	......	...	21
0	...	.. ..	6	40	1.944	*f*	0	...	.. ..	...	...	1.954	*f*	0	...	.. ..	12	110	1.935	*f*	22
0	...	.. ..	6	25	......	...	0	...	.. ..	2	25	1.955	*f*	0	...	.. ..	13*	115	......	...	23
1	...	.. ..	4	15	1.948	*u*	0	...	.. ..	2	30	1.947	*f*	0	...	.. ..	16	145	......	...	24
1	...	.. ..	3	35	1.932	*u*	0	...	.. ..	6	50	1.944	*f*	0	...	.. ..	16	125	......	...	25
0	...	.. ..	7	55	......	...	0	...	.. ..	6	60	......	...	0	...	.. ..	15	125	......	...	26
0	...	.. ..	7*	35	1.953	*f*	0	...	.. ..	9	140	1.939	*s*	1	*i*	3 30	...	...	......	...	27
0	...	.. ..	8*	40	1.944	*f*	0	...	.. ..	11	165	1.947	*f*	1	*i*	.. ..	...	...	......	...	28
0	...	.. ..	8	85	1.940	*f*	2	*i*	23 39	10	160	1.946	*f*	1	*i*	.. ..	...	...	......	...	29
0	...	.. ..	...	...	1.940	*f*	1	*i*	.. ..	11	115	......	...	0	...	.. ..	...	...	......	...	30
1	*i*	1 25	...	...	......	...								0	...	.. ..	...	...	......	...	31
0.3			8.2	70.8	1.944		0.4			8.8	75.9	1.948		0.1			11.2	96.8	1.939		Mean

*Revision of value originally broadcast.

Greenwich mean time for ending of storms: 9[h], October 18; 17[h], November 1; 12[h], November 3; 22[h], November 30; 12[h], [December] 29.

spots: (1) the number of groups of spots and (2) the total number of spots. It is to be noted that sunspot-numbers such as those from Zürich can be obtained from the number of groups and spots given in the Table by the formula $N=k\ (10g+s)$, where the mean value of k for Mount Wilson was 0.53 during 1936.

Kennelly-Heaviside Layer heights, Washington, D. C., October to December, 1936
(Nearest hour, Greenwich mean time, of all observations is 17)

Date	Freq.	Ht.	Date	Freq.	Ht.	Date	Freq.	Ht.	Date	Freq.
1936	*kc/sec*	*km*	*1936*	*kc/sec*	*km*	*1936*	*kc/sec*	*km*	*1936*	*kc/sec*
Oct. 7	2,500	120	Oct. 28	4,400	250	Nov. 18	12,400	460	Dec. 9	11,400
" "	3,200	130	" "	6,200	270	" "	12,600	*	" "	12,200
" "	3,600	150	" "	9,000	290	" 25	2,500	110	" "	12,400
" "	3,700	*	" "	10,200	300	" "	3,300	140	" 16	2,500
" "	3,800	220	" "	11,000	330	" "	3,420	190	" "	3,170
" "	3,850	200	" "	12,000	380	" "	3,450	280	" "	3,350
" "	4,400	230	" "	12,400	430	" "	3,800	230	" "	3,400
" "	7,000	280	" "	12,600	480	" "	4,250	250	" "	3,400
" "	9,800	350	" "	12,800	*	" "	4,400	240	" "	3,500
" "	11,000	380	Nov. 4	2,500	120	" "	5,800	240	" "	3,500
" "	11,000	460	" "	3,400	180	" "	7,000	270	" "	4,400
" "	11,800	450	" "	3,500	*	" "	8,600	290	" "	6,200
" "	12,200	500	" "	3,630	240	" "	9,800	320	" "	8,600
" "	12,400	*	" "	4,000	220	" "	9,800	360	" "	9,800
" 14	2,500	120	" "	4,400	240	" "	10,800	340	" "	10,600
" "	3,500	150	" "	5,400	260	" "	10,800	400	" "	10,600
" "	3,700	*	" "	7,000	270	" "	11,600	390	" "	11,200
" "	3,830	250	" "	9,800	270	" "	11,600	460	" "	11,200
" "	4,000	230	" "	10,600	280	" "	12,600	480	" "	11,800
" "	4,400	250	" "	12,600	370	" "	12,800	*	" "	12,000
" "	6,200	270	" "	12,600	490	Dec. 2	2,500	120	" 23	2,500
" "	8,600	290	" "	13,200	420	" "	3,000	130	" "	3,300
" "	9,400	320	" "	13,600	*	" "	3,530	180	" "	3,420
" "	11,000	350	" 11	2,500	120	" "	3,550	*	" "	3,420
" "	11,000	390	" "	3,500	130	" "	3,560	290	" "	3,800
" "	14,000	370	" "	3,570	270	" "	4,000	220	" "	4,400
" "	14,000	430	" "	3,800	240	" "	4,400	220	" "	6,200
" "	12,200	430	" "	4,400	250	" "	7,000	260	" "	9,400
" "	12,400	*	" "	8,200	260	" "	9,000	280	" "	10,200
" 21	2,500	110	" "	9,800	290	" "	11,000	310	" "	11,200
" "	3,500	120	" "	11,000	300	" "	12,400	370	" "	11,200
" "	3,700	*	" "	12,600	350	" "	12,400	560	" "	12,200
" "	3,780	270	" "	13,400	370	" "	13,000	460	" "	12,400
" "	3,850	250	" "	13,400	410	" "	13,200	*	" 30	2,500
" "	7,000	270	" "	14,000	380	" 9	2,500	120	" "	3,380
" "	9,000	280	" "	14,000	540	" "	3,450	170	" "	3,400
" "	11,000	310	" "	14,000	500	" "	3,480	*	" "	3,750
" "	12,000	330	" "	15,000	*	" "	3,500	200	" "	4,400
" "	12,000	400	" 18	2,500	130	" "	3,550	180	" "	6,200
" "	12,800	360	" "	3,300	170	" "	3,580	280	" "	8,600
" "	12,800	600	" "	3,380	290	" "	4,000	240	" "	10,200
" "	13,200	410	" "	3,500	230	" "	4,400	250	" "	11,800
" "	13,400	*	" "	4,400	240	" "	6,200	260	" "	11,800
" 28	2,500	130	" "	7,000	270	" "	8,200	280	" "	12,800
" "	3,400	150	" "	9,000	290	" "	10,200	300	" "	12,800
" "	3,500	*	" "	11,000	320	" "	11,000	320	" "	13,400
" "	3,680	270	" "	11,800	360	" "	11,000	350	" "	13,600
" "	3,900	240	" "	12,200	410	" "	11,400	340	" "	13,800

* = No value obtained.

Mount Wilson Observatory is now supplying corrections and additions to the sunspot-data which are broadcast in the *URSI*gram. So far as possible, these additional and corrected values will be used in this tabular summary and will be designated as such in footnotes to the Table.

Beginning January 1, 1934, the magnetic information of the *URSI*-gram is for Cheltenham, Maryland, instead of Tucson, Arizona. In addition to this change in observatory, the data cover the 24 hours ending 8 A. M., 75° west meridian mean time, instead of the 24 hours ending at 7 A. M., 105° west meridian mean time.

The columns headed solar constant show (1) the value in calories of the solar constant, and (2) by letters *s*, *f*, and *u* whether the determination was satisfactory, fair, or unsatisfactory, respectively.

In accordance with information received from Dr. C. G. Abbot, Secretary of the Smithsonian Institution, transfer from Table Mountain to Montezuma solar-constant values was made as of October 23, 1934. Table Mountain for a considerable time has been 0.012 calorie above Montezuma, and above the scale of 1913 to 1930. Hence the value of October 23, 1934, and succeeding values are on a scale 0.012 calorie lower than previous ones.

The data for the table of Kennelly-Heaviside Layer heights which is self-explanatory are supplied by the National Bureau of Standards.

C. C. Ennis

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C.

PROVISIONAL SOLAR AND MAGNETIC CHARACTER-FIGURES, MOUNT WILSON OBSERVATORY OCTOBER, NOVEMBER, AND DECEMBER, 1936

Greenwich mean time						Range Hor. int.
Beginning			Ending			
1936	*h*	*m*	*d*	*h*	*m*	γ
Oct. 16	15	01	18	10	...	133
Nov. 28	23	38	29	22	..	212
Dec. 27	3	28	28	18	..	127

The magnetic storm of October 16-18 occurred during cloudy weather at Mount Wilson. An active group which crossed the central meridian on October 17.1 was 25° south of the center of the solar disc when the storm began, while another much smaller group, which crossed the central meridian on October 16.8, was 7° north of the center.

At the time of the November storm two large active spot-groups were nearly at the central meridian, one crossing it on November 29.4, 16° north, the other on November 29.4, 11° south of the center of the solar disc.

The northern group, which was approaching the central meridian at the beginning of the November storm, returned and had just crossed the meridian (December 26.9) when the December storm began. Several other groups were then on the Sun, but bad weather, which prevented all solar observations at Mount Wilson from December 26 to 31, made it impossible to say which was the most active at the time of this storm.

On October 31 a sudden increase in the horizontal intensity of 29 gammas at $1^h 25^m$, GMT, was followed by a small magnetic storm with a range of 74 gammas.

Day	October 1936								November 1936								December 1936							
	K_2		$H\alpha B$		$H\alpha D$		No. groups	Mag'c char.	K_2		$H\alpha B$		$H\alpha D$		No. groups	Mag'c char.	K_2		$H\alpha B$		$H\alpha D$		No. groups	Mag'c char.
	A	B	A	B	A	B			A	B	A	B	A	B			A	B	A	B	A	B		
1	4	3	3[d]	3	3	2	12	0	....	....	....	....	....	....	....	0	....	....	....	....	....	....	14	0
2	....	....	....	....	....	....	....	0	4	4	4	4	2	1	9[o]	0.5	5	4	4	3	2	1	13[h]	0
3	4	4	4	4	3	3	8[o]	0	4	4	5	4	1	2	10	1	5	3	....	....	....	....	..[o]	0
4	4	4	4	4	3	3	11	0	4	4	4	4	2	2	11[h]	0.5	....	....	....	....	....	....	..	0.5
5	4	4	4	4[c]	3	2	11[h]	0	4	3	4	4[c]	2	2	12	0.5	5	3	5	3	3	1	13	0
6	4	4	3	3	3	1	9[o]	0	4	3	4	3	2	1	14[h, i]	0.5	5	4	4	4	3	2	13	0
7	3	3	4	3	4	1	10	0.5	4	3	4[d]	3	2	1	12	0.5	....	....	....	....	....	....	10	0
8	4	2	4	2	3	2	11	0.5	4	3	3[d]	3	3	1	12[b]	0	5	4	4	3	3	3	13	0
9	3	2	4	2	4	2	11	0.5	4	4	....	....	....	....	13	0.5	4	3	4	3	2	3	11	0
10	3	2	3	2	4	2	8	1	....	....	....	....	....	....	15[b]	0	4	4	4	4	3	2	9[o]	0
11	3	3	3	3	4	3	9[h]	0	....	....	4	4	3	1	11[o]	0.5	3	4	3	3	3	2	11	0.5
12	3	4	4	4[c]	4	3	9[o]	0	4	3	4	3	3	1	12[i]	0	3	4	3	3	3	2	7	0.5
13	3	3	3	3	5	4	8	0	4	4	4	4	2	1	11[i]	0	....	....	....	....	....	....	....	0
14	3	3	4[d]	1	5	5	9	0	....	....	....	....	....	....	9[o]	0	....	....	....	....	....	....	....	0
15	3	3	3	1	5	5	8	0.5	3	4	3	4	4	1	8	0.5	....	....	....	....	....	....	....	0
16	....	....	....	....	....	....	....	1	....	....	....	....	....	....	9	0.5	....	....	....	....	....	....	....	0
17	....	....	....	....	....	....	..[i]	1.5	3	2	3	2	3	3	8	0.5	3	2	3	2[c]	3	1	3[h]	0
18	....	....	....	....	....	....	..[i]	0.5	3	1	3[d]	1	3	3	7	0.5	3	3	3	3	3	1	6	0
19	....	....	....	....	....	....	....	0	3	2	3	2	4	1	4	0	....	....	....	....	....	....	....	0
20	3	2	3	2	4	2	6	0	3	1	3	1	4	1	2	0	3	3	3[d]	3	3	1	8[i]	0
21	3	2	3[d]	2	4	3	7	0	2	2	2	2	3	1	1	0	3	2	3	2	3	2	10	0
22	3	2	3[d]	2	3	2	6	0	....	....	....	....	....	....	..[i]	0	3	1	3[d]	1	3	2	12	0
23	3	3	3	3	3	2	6	0.5	2	2	2	2	3	0	2	0	3	1	3	1	2	1	13	0
24	3	3	3[d]	2	3	2	4	1	3	1	2?[d]	1?	3	0	2	0	4	3	4[d]	3[c]	2	0	16[i]	0
25	3	2	3	3	3	0	3	0.5	3	2	3[d]	1	3	1	6[b]	0	5	4	4	3	2	0	16	0
26	3	3	3	4[c]	4	1	7	0	3	1	3[d]	1	2	0	6	0	4	4	4[d]	3	2	1	15	0
27	3	3	3	3	4	1	7[o, h]	0	3	3	3	2	2	0	9	0	....	....	....	....	....	....	....	0.5
28	3	3	3	3	4	1	8	0	4	4	3	4	2?	1?	11	0.5	....	....	....	....	....	....	....	1.5
29	3	2	3	2	3	1	8	0	5	5	4	4[c]	3	1	10[o, h]	2	....	....	....	....	....	....	....	0
30	....	....	....	....	....	....	....	0	....	....	....	....	....	....	11	0	....	....	....	....	....	....	....	0
31	....	....	....	....	....	....	....	1									....	....	....	....	....	....	....	....
Mean	3.2	2.9	3.3	2.7	3.7	2.2	8.2	0.3	3.5	2.8	3.3	2.7	2.7	1.1	8.8	0.3	3.9	3.1	3.6	2.8	2.6	1.5	11.2	0.1

NOTE—For an explanation of these tables see this JOURNAL, 35, 47-49 (1930). The character-figures of solar phenomena are estimated from the spectroheliograms which are made with a 2-inch solar image, usually in the early morning. The very bright chromospheric eruptions are reported in these notes if observed at any time during the day.

?Indicates an uncertain value which should be given low weight. [illegible] (h) more than 30° from the center of the disc.

A SOLAR ERUPTION OF NOVEMBER 27, 1936, AND SIMULTANEOUS DISTURBANCES IN EARTH'S MAGNETISM, EARTH-CURRENTS, AND THE IONOSPHERIC REGIONS

Spectrohelioscope-observations—From 16^h 50^m to 16^h 58^m GMT on November 27, 1936, an extremely bright circular flocculus was observed. Its approximate position was 6° South and 21° East.

Magnetic record—A sudden commencement occurred in all three elements at $16^h\,50^m$ GMT, terminating at $17^h\,00^m$ after very small changes. These changes would hardly be worthy of note but for their simultaneity with a solar eruption.

Earth-current record—A small change occurred in all four lines at $16^h\,50^m$ to $17^h\,00^m$ GMT.

Ionosphere-record—On this occasion continuous recording at a single frequency of 4800 kc had been interrupted to allow of measurements over a range of frequencies. Between $16^h\,51^m$ and $16^h\,54^m$ no reflections were obtained using transmission-frequencies of 7800 to 9000 kc. Before and after this interval, reflections were consistently recorded.

This is the third occasion on which disturbances in magnetic, earth-current, and ionospheric records have been observed to occur simultaneously with a solar eruption. The two previous occasions, April 8 and November 6, 1936, have already been reported upon. On this particular occasion the magnitudes of the effects were much smaller than on the two previous occasions but the agreement in times of occurrence with that of the solar eruption was no less definite.

F. T. Davies, O. W. Torreson,
W. E. Scott, H. E. Stanton

Huancayo Magnetic Observatory,
Huancayo, Peru, December 6, 1936

PRINCIPAL MAGNETIC STORMS

SITKA MAGNETIC OBSERVATORY

OCTOBER TO DECEMBER, 1936[1]

(*Latitude 57° 03'.0 N., longitude 135° 20'.1 or 9ʰ 01ᵐ.3 W. of Gr.*)

October 9-10—A moderate disturbance began about $7^h.5$ GMT, October 9, and continued with gradually-increasing intensity until at about $8^h\ 21^m$, October 10, the amplitudes suddenly became very large and the periods short, continuing so for about an hour. After this the elements gradually quieted down, and by 17^h, October 10, the disturbance was practically over.

October 16-17—After several days of slight activity, a moderate disturbance began about 15^h GMT, October 16, and continued for 24 hours. The chief characteristics of the storm were short periods of moderate amplitude and large changes in the average values of the elements, first in one direction and then in the other.

October 31—A slight disturbance began abruptly about $1^h\ 24^m$ GMT, October 31. After the first quick, short movement there was only negligible activity until about 9^h, when the disturbance suddenly assumed the proportions of a major storm. All the elements fluctuated wildly for about five hours, and then gradually settled back to normal. The storm was over by 17^h, though minor oscillations continued for some hours.

November 28-29—A storm began very sharply at $23^h\ 38^m$ GMT, November 28, but remained relatively quiet for four hours afterward. Then it became quite active for several hours but had nearly disappeared by 7^h, November 29. A few minutes later there was a second abrupt beginning, this time of decidedly greater intensity. About 10^h it began to quiet down and by 14^h the storm had ended.

December 27-28—Though this storm had a sharp beginning at $3^h\ 28^m$ GMT, December 27, there was no important activity until about 24 hours later. Then the intensity of the disturbance gradually increased but still remained moderate until about 10^h, December 28. After this the oscillations were large and rapid until about 14^h, when the elements began to quiet down. The storm ended at 18^h, December 28.

JOHN HERSHBERGER, *Observer-in-Charge*

CHELTENHAM MAGNETIC OBSERVATORY

OCTOBER TO DECEMBER, 1936[1]

(*Latitude 38° 44'.0 N., longitude 76° 50'.5 or 5ʰ 07ᵐ.4 W. of Gr.*)

October 9-10—A mild disturbance began about $7^h\ 30^m$ GMT, October 9. It continued until about 22^h, October 10. The perturbations were irregular and not of great range. The more severe part of the storm was from 1^h to 10^h, October 10.

October 16-17—A disturbance began about 15^h GMT, October 16. It ended about $14^h\ 30^m$, October 17. It was not of great amplitude.

[1]Communicated by R. S. Patton, Director, United States Coast and Geodetic Survey.

The outstanding feature was an increase in declination and horizontal intensity and a decrease in vertical intensity at $5^h 25^m$, October 17.

November 1—A sudden commencement of a disturbance occurred at $1^h 26^m$ GMT, November 1, when the horizontal intensity increased about 35 gammas and the vertical intensity increased about four gammas. The sudden commencement was preceded for about 20 minutes with short-period oscillations of very small amplitude. The disturbance ended about 24^h the same day.

November 28-29—A short but active storm began with a sudden commencement at $23^h 37^m$ GMT, November 28. The declination increased eastward abruptly by 1′ followed almost immediately by a decrease of 5′. The horizontal intensity decreased abruptly by 18 gammas followed almost immediately by an increase of 96 gammas. The beginning of the storm for the vertical intensity was not so well defined. There were irregular oscillations for about 12 hours when the activity changed to short-period oscillations which ended about 24^h, November 29. Between 3^h and 4^h, November 29, a bay occurred when the horizontal intensity increased and recovered about 140 gammas, the vertical intensity decreased and recovered about 100 gammas and the declination decreased and recovered about 23′. Again between 7^h and 8^h the horizontal intensity decreased and recovered about 80 gammas, the vertical intensity decreased and recovered about 160 gammas, and the declination increased and recovered about 38′. The ranges during the storm were: Declination, 48′; horizontal intensity, 268 gammas; and vertical intensity, 246 gammas.

December 27-29—A disturbance began with a sudden commencement at $3^h 30^m$ GMT, December 27, when the declination and horizontal intensity decreased and the vertical intensity increased through small amplitudes followed by an abrupt reversal in declination of 1′, in horizontal intensity of 28 gammas and in vertical intensity of three gammas. The perturbations ended gradually about 12^h, December 29, the most disturbed period being during the entire day of December 28. The ranges were: Declination, 34′; horizontal intensity, 39 gammas; vertical intensity, 72 gammas.

ALBERT K. LUDY, *Observer-in-Charge*

TUCSON MAGNETIC OBSERVATORY

OCTOBER TO DECEMBER, 1936[1]

(*Latitude 32° 14′.8 N., longitude 110° 50′.1 or $7^h 23^m.3$ W. of Gr.*)

October 16-17—A disturbance of moderate intensity was characterized by abrupt starts in D and H at $15^h 01^m$ GMT, October 16. The storm, which consisted of several large bays with superimposed short-period activity in D and H, ended at about 14^h, October 17. Ranges were: H, 126 gammas; Z, 51 gammas; D, 15′.

October 31—This disturbance, although very moderate, was of interest because of an abrupt commencement in all three elements at $1^h 24^m$ GMT, October 31. H increased 37 gammas in four minutes.

[1]Communicated by R. S. Patton, Director, United States Coast and Geodetic Survey.

After some short-period activity and several bays in D and H, each lasting about an hour, the storm ended at 14^h, October 31. Ranges were: H, 81 gammas; Z, 26 gammas; D, 9.5′.

November 28-29—A severe storm began with sudden commencements on all three elements at $23^h\ 37^m$ GMT, November 28. H decreased about two gammas and then increased 47 gammas within an interval of two minutes. All elements displayed several long bays and D and H were characterized by severe superimposed short-period activity. In the interval from $3^h\ 48^m$ to $4^h\ 51^m$, November 29, D rose to a maximum and then subsided, covering a range of 23′. By 13^h, November 29, all of the violent activity had ceased, and following a period of minor short-period activity, the disturbance ended at about 22^h, November 29. Ranges were: H, 201 gammas; Z, 26 gammas; D, 29′.

December 27-28—A sudden commencement on all three elements occurred at $3^h\ 29^m$ GMT, December 27. This was followed by a quiet period lasting until $23^h\ 09^m$ on the same day, when a moderate storm began with a sudden commencement of H. The disturbance characterized by several long bays with superimposed moderate activity of intermediate period in D and H, ended at 23^h, December 28. Ranges were: H, 109 gammas; Z, 21 gammas; D, 16′.

J. WALLACE JOYCE, *Observer-in-Charge*

APIA OBSERVATORY

OCTOBER TO DECEMBER, 1936

(Latitude 13° 48′.4 S., longitude 171° 46′.5 or $11^h\ 27^m.1$ W. of Gr.)

October 9-10—A moderate disturbance was introduced at $7^h\ 28^m$ GMT, October 9, by a slight sudden rise in horizontal intensity. The H-trace showed undue fluctuations and gradually fell to reach a minimum of 34921 gammas at $7^h\ 41^m$, October 10, thereafter gradually returning to normal.

October 16-18—A slight sudden rise of horizontal intensity at $14^h\ 59^m$ GMT, October 16, introduced a fairly intense disturbance. H began to fall at once and was still falling rapidly when the illumination unfortunately failed at 4^h, October 17. The trace was still somewhat disturbed October 18.

October 31—Commencing at $1^h\ 23^m$ GMT, October 31, with a sudden rise of 22 gammas in H and also rises in Z and D a moderate disturbance caused these three elements to remain disturbed only for the remainder of that day. H fell continuously to reach a minimum of 34908 gammas at $12^h\ 15^m$, October 31, and then gradually returned to normal.

November 28-29—A major magnetic storm was introduced at $23^h\ 35^m$ GMT, November 28, by a sudden rise of 51 gammas, bringing the horizontal intensity to a maximum of 35125 gammas. H then fell rapidly with a large sudden fall at $4^h\ 25^m$, November 29, and another on the same day at $9^h\ 33^m$ to bring H to a minimum of 34851 gammas at $9^h\ 41^m$, November 29, giving a range in horizontal intensity of 274 gammas during the disturbance. The H-trace rapidly returned to normal. Large fluctuations occurred in vertical intensity which varied sympathetically with H. Declination also showed considerable movement.

December 27-29—A slight disturbance commenced at about 3^h GMT, December 27 and caused H to fluctuate and remain below normal during December 28 and 29.

H. F. Baird, *Acting Director*

Huancayo Magnetic Observatory

November to December, 1936

(*Latitude 12° 02'.7 S., longitude 75° 20'.4 or 5^h ^{m}01.4 W. of Gr.*)

Greenwich mean time							Range		
Beginning			Ending				Decl'n	Hor. int.	Ver. int.
1936	*h*	*m*	*d*	*h*	*m*		′	γ	γ
Nov. 2	14	20	2	14	32		3	127	8
Nov. 6	16	10	6	16	30		2	67	8
Nov. 10	16	41	10	18	00		3	176	16
Nov. 15	12	00	15	18	00		5	198	33
Nov. 27	16	50	27	17	00		1	16	1
Nov. 28	23	37	29	22	00		14	264	56

November 2—This was a very brief disturbance with sudden commencement in all three elements. After $14^h\ 20^m$ GMT, H increased seven gammas in one minute, decreased 18 gammas in two minutes, increased 127 gammas in three minutes, and decreased 60 gammas to normal value at $14^h\ 32^m$. After $14^h\ 22^m$ D decreased 1′ in two minutes, increased 3′ in three minutes, and decreased 2′ in five minutes to normal value at $14^h\ 32^m$. After $14^h\ 22^m$ Z increased six gammas in four minutes and then decreased eight gammas in four minutes to normal value at $14^h\ 32^m$. Prior to and following this 12-minute interval of disturbance the magnetic records were undisturbed.

November 6—See special report in this Journal, **41**, 409-410 (1936).

November 10—This was a brief disturbance in which H experienced several very sharp bays and peaks, among which occurred a change of 176 gammas from maximum to minimum in a period of five minutes. D and Z showed more perturbations than usual but the normal trends were maintained.

November 15—In a brief disturbance H showed a large bay between 14^h and 18^h GMT, with a decrease in this interval of 198 gammas. Z increased 11 gammas, from $14^h\ 20^m$ to $15^h\ 20^m$. D showed very little change.

November 27—This was a very small magnetic disturbance with sudden commencement in all three elements, found to be simultaneous with a brief eruption and with disturbances on earth-current and ionosphere-records. Each magnetic element increased slightly for three minutes and then returned to normal value in seven minutes.

November 28—This magnetic storm was marked by a sudden commencement in all three elements. H increased 64 gammas in three minutes. Z increased 11 gammas and D increased 1′ in the same interval. Following the sudden commencement, H experienced one large

bay over a period of 13 hours, with a minimum value for the storm at the middle of this period. After 12^h on November 29, H showed only minor perturbations superposed on the normal diurnal trend. Both D and Z showed unusual fluctuations although diurnal trends were maintained.

December 27-28—A sudden commencement occurred at $3^h\,28^m$ GMT, December 27. From $3^h\,28^m$ to $3^h\,33^m$ H increased 34 gammas, Z increased 5 gammas, and D increased 1′. The remainder of the trace for December 27 was only slightly disturbed and that for December 28 showed moderate disturbance.

The month of December was very quiet, 29 days being classified as "0" days and the other two days as of character "1".

Frank T. Davies, *Observer-in-Charge*

Watheroo Magnetic Observatory

October to December, 1936

(*Latitude, 30° 19′.1 S., longitude, 115° 52′.6 or $7^h\,43^m.5$ E. of Gr.*)

October 9-10—A minor disturbance was ushered in by a sudden commencement at $7^h\,26^m\,50^s$ GMT, October 9, as shown by the record from the vertical-intensity inductometer. Westerly D decreased 4′ in seven minutes, H increased 16 gammas in six minutes, and the numerical value of Z decreased 7 gammas in six minutes. The period of slightly disturbed magnetic conditions continued until 16^h, October 10.

October 16-18—A small disturbance without marked features lasted from 15^h, October 16, to 14^h GMT, October 17. Ranges were: D, 18′; H, 136 gammas; Z 102 gammas. This disturbance was followed by another of low intensity on October 18 from 4^h to 10^h.

October 31—This moderate disturbance began with a sudden commencement of which the time as shown by the vertical-intensity inductometer was $1^h\,23^m\,15^s$ GMT, October 31. Westerly D decreased 2′ in one minute followed by an increase of 6′ in four minutes, H increased 18 gammas in six minutes, and the numerical value of Z decreased 9 gammas in one minute followed by an increase of 24 gammas in four minutes. The disturbance continued until 16^h, October 31. Ranges were: D, 23′; H, 150 gammas; Z, 192 gammas.

November 28-29—This storm began with a sudden commencement at $23^h\,37^m\,30^s$ GMT, November 28. D increased 6′.5 during the first minute and dropped back about 3′ during the next minute. Movements in H were so rapid that the record was lost for the first three minutes. Z increased 30 gammas in three minutes. Ranges were: D, 23′.5; H, 178 gammas; Z, 189 gammas. The disturbance ended at 16^h, November 29.

December 27-28—This disturbance began quite sharply and was followed by a second sharp impulse at $3^h\,28^m\,12^s$ GMT, December 27. The elements continued slightly disturbed throughout December 27, increased to a moderate disturbance during the early hours of December 28, and died out rather suddenly at about 18^h on that date. Ranges were: D, 16′.5; H, 135 gammas; Z, 164 gammas.

J. W. Green, *Observer-in-Charge*

NOTES

1. *Institute of Geophysics and Meteorology, University of Latvia*—The Institute of Meteorology and the Institute of Physical Geography, which hitherto had been two separate institutions of the University of Latvia, Riga, have now been united under the name of the "Institute of Geophysics and Meteorology." The head of the Institute is Prof. Dr. Rudolf Meyer. Prof. Meyer is also directing its meteorological work. The purely geophysical work—particularly oceanography and terrestrial magnetism—is being conducted by Docent Leonids Slaucitajs.

2. *Short-wave broadcast of scientific data*—A regular schedule of broadcasts of cosmic data and scientific news was inaugurated February 1, 1937, by the World Wide Broadcasting Foundation's short-wave station W1XAL, Boston, Massachusetts. Every afternoon this station will announce in plain English technical data on observations of sunspots, solar radiation, magnetism, ionized layer-heights, and other phenomena that have been observed at various stations during the same day. The primary purpose is to make such information available internationally and to interest laymen inclined to make observations.

Through arrangements effected by Walter S. Lemmon, founder and president of the World Wide Broadcasting Foundation, the facilities of the station W1XAL are made available for the extension of the Ursigram service in cooperation with Science Service. The station, licensed for international broadcasting on four frequencies, now operates on 20,000 watts and is heard with good volume in almost all parts of the world. The broadcasts should be, accordingly, available to listeners anywhere who are suitably equipped with standard all-wave receivers.

The broadcasts will be heard daily from 4:55 to 5:00 p. m. Eastern Standard Time on 11.79 megacycles (25.4 meters) and weekly summaries on Monday evenings from 8:30 to 8:45 p. m. Eastern Standard Time on 6.40 megacycles (49.6 meters). The daily broadcasts will cover current data; the Monday evening broadcasts will be weekly compilations.

The program inaugurating the new service included brief talks by Dr. A. E. Kennelly of Harvard University, Dr. Harlow Shapley, Director of Harvard College Observatory, Dr. Loring B. Andrews, Chairman of W1XAL Program Committee, and Watson Davis, Director of Science Service, Washington, D. C.

The remarks by Mr. Davis included the following statements: "The inauguration of this regular broadcasting of scientific news and data is an event significant to both science and radio broadcasting. . . . For nearly seven years Science Service in cooperation with the American Section of the International Scientific Radio Union has collected and distributed daily information about the fundamental inconstants of nature. From remote corners of the Earth and from busy scientific laboratories has come information about solar radiation, magnetic conditions, sunspots, aurora, and the heights of the ionized layers that affect radio communication. The Army Radio Net has brought some of this information to Washington and the Navy has also lent its valuable cooperation in the broadcasting of the daily cosmic-data messages. This is done in international Morse code from NAA, Arlington, at 5:30 p. m. Eastern Standard Time on 9250 kilocycles and 4390 kilocycles. . . . Now the World Wide short-wave station W1XAL in this broadcast is inaugurating its regular schedule of cosmic-data and other scientific broadcasts which will make such information available to the large international audience that it reaches. It will speed the production of scientific results in many cases by many weeks."

3. *Anniversary of discovery of South Pole*—According to a wireless dispatch to *The New York Times*, the twenty-fifth anniversary of Roald Amundsen's discovery of the South Pole was marked December 14, 1936, by a meeting in the polar museum aboard Dr. Fridtjof Nansen's vessel *Fram*, in which tablets were unveiled in memory of Nansen and Captain Otto Sverdrup by Knud Ringnes, Chairman of the *Fram* Committee, and in memory of Amundsen by Knut Doaaas.

4. *December number*—It is regretted that the distribution of the December number of the Journal was unavoidably delayed by the flooding of the Ohio River at Cincinnati, Ohio, where it is printed. The River, overflowing its banks invaded a large portion of the City causing much damage and paralyzing business for several weeks.

5. *Corrigenda*—The following changes should be made in the December 1936 number of the Journal: On page 337, the author desires that the word "oscillations" in the first paragraph, line 8, and in the second paragraph, line 4, be changed to "pulsations"; that the third word in line 5 of the second paragraph be changed to read "pulsation", and the last word in the same line read "micropulsations"; that the word "oscillations" in the sixth line of the third paragraph read "rapid micropulsations." At the end of the first paragraph the following sentence is to be added: "Only one certain visual observation of the rapid micropulsations has been made; it gives a period of 1.1 second for the whole oscillation."

The reference at the end of the fifth paragraph of page 347 and in the last line on page 349 may now be completed to read "SitzBer. IIa, **145**, 495-502, 1936."

On page 353, fifth paragraph, sixth line, the word "only" should be inserted before the word "two," so that the four last words of the sixth line will be "only two of them." The name of the last station in Table 1, page 353, should read "Balerna (Chiasso)" instead of "Balerma (Chiasso)".

On page 377, Table 2, Case A, column n_3, seventh and eighth lines should read 1.53×10^{10} and 4.68×10^{10}, respectively.

On page 393, ninth line from bottom read "P. A. Müller" instead of "P. K. Müller" and on page 394, second line from bottom read "Chappe d'Auteroche's" instead of, "Cappe d'Auteroche's."

6. *Magnetic work in Canada*—Several of the governmental departments of Canada have been amalgamated into two new departments. As a result of this amalgamation, the magnetic and seismological work which was formerly divided between the Meteorological Service of Canada and the Dominion Observatory, Department of the Interior, was consolidated and put under the Dominion Observatory in the Department of Mines and Natural Resources. This work is now under the direction of R. M. Stewart, Dominion Observer, whose former title was "Director of the Dominion Observatory." The Meteorological Service is now under the Department of Transport, Air Service Branch, instead of under the Department of Marine, as formerly. This service remains under the direction of J. Patterson, whose title has been changed to "Controller of Meteorological Services."

7. *Personalia*—Dr. *Mario Bossolasco* was appointed professor of geophysics and director of the Institute of Geophysics and Geodesy of the University of Messina, effective January 1, 1937.

The British Royal Astronomical Society has awarded its gold medal to Dr. *Harold Jeffreys*, university reader in geophysics at the University of Cambridge, for his researches into the physics of the Earth and other planets and for his contributions to the study of the origin and age of the solar system.

Captain *Oscar Wisting*, the Norwegian arctic explorer, who was one of the men with Amundsen when he reached the South Pole on December 14, 1914, and who was second in command of the *Maud* during Amundsen's arctic expeditions of 1918-25, died on board the *Fram*, which is now kept on land at Oslo as a polar museum and of which he was the custodian.

LIST OF RECENT PUBLICATIONS

By H. D. Harradon

A—Terrestrial and Cosmical Magnetism

Bangkok, Royal Survey Department. Report on the operations of the Royal Survey Department, Ministry of Defence, for the year 1934-35. Bangkok, Printing Office, R. Surv. Dept., 1936 (32 with 2 index maps). 29 cm. [On page 29 is a table of results of magnetic observations made at various points in Siam 1907-1929.]

Bartels, J. Aufschlüsse über die Ionosphäre aus der Analyse sonnen- und mondentägiger erdmagnetischer Schwankungen. Zs. Geophysik, Braunschweig, Jahrg. 12, Heft 7/8, 1936 (368-376). [Aus den tagesperiodischen erdmagnetischen Variationen lässt sich auf die Ionisation und die Bewegung in der Ionosphäre schliessen. Insbesondere eignen sich dazu die mondentägigen Variationen L, weil ihre Entstehung physikalisch einfacher ist als diejenige der sonnentägigen Variationen S, Das beobachtete Verhältnis der Intensität von L zu S macht es wahrscheinlich, dass in den Schichten unterhalb der Ionosphäre keine so grossen taglichen Temperaturschwankungen vorkommen wie manchmal angenommen. Für 12jährige Beobachtungen der Horizontalintensität in Huancayo, Peru, werden L und S in ihrer Abhängigkeit von der Jahreszeit, dem Fleckenzustand der Sonne und dem erdmagnetischen Störungszustand in vorläufiger Form mitgeteilt und besprochen. Die lunare Variation L im Südsommer ist an dieser Station die grösste bisher für irgendein Observatorium gefundene, und zwar sowohl ihrer absoluten Grösse nach wie im Vergleich zur solaren Variation S; sie eignet sich deshalb besonders für die weitere Analyse.]

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Hasegawa, M. On the type of the diurnal variations of the terrestrial magnetism on quiet days. Tokyo, Proc. Imp. Acad., v. 12, No. 7, 1936 (88-90).

A statistical study of the type of diurnal variations of terrestrial magnetism on quiet days. Tokyo, Proc. Imp. Acad., v. 12, No. 7, 1936 (185-187).

Analysis of the field of diurnal variation of terrestrial magnetism of the different types. Tokyo, Proc. Imp. Acad., v. 12, No. 8, 1936 (221-224).

Representation of the field of diurnal variation of terrestrial magnetism by the method of graphical integration. Tokyo, Proc. Imp. Acad., v. 12, No. 8, 1936 (225-228).

On the progressive change of the field of diurnal variations of terrestrial magnetism. Tokyo, Proc. Imp. Acad., v. 12, No. 9, 1936 (277-280).

Haussmann, K. Magnetische Reichsaufnahme. Mitt. Markscheidew., Freiberg, Heft 2, 1936 (146-148). [Discussion of publication of H. Reich on the magnetic survey of Germany.]

Judson, E. B. Comparison of data on the ionosphere, sunspots, and terrestrial magnetism. New York, N. Y., Proc. Inst. Radio Eng., v. 25, No. 1, 1937 (38-46).

Krogness, O., and K. F. Wasserfall. Results from the magnetic station at Dombås 1916-33. Published by Det Magnetiske Byrå, Bergen. Bergen, Pub. Inst. Kosmisk Fysikk, No. 9, 1936 (110 with figs, and graphs). 31 cm.

Lovö. Ergebnisse der Beobachtungen des magnetischen Observatoriums zu Lovö (Stockholm) im Jahre 1932. Stockholm, Sjökarteverket, 1936 (103). 32 cm.

Malamphy, M. C. Magnetic prospecting in Santa Catharina, Brazil. Geophysics, Houston, Texas, v. 1, No. 1, 1936 (23-47).

Molle, A., et L. Koenigsfeld. Observations magnétiques faites à Elisabethville (Congo Belge) pendant l'Année Internationale Polaire par A. Molle, et résultats des observations par L. Koenigsfeld. Préface de M. M. Dahalu. Bruxelles, Marcel Hayez, 1936 (120 with 3 pls.). 30 cm. [Université de Liége, Inst. Astr. Géod., Physique du Globe, No. 4.]

Petrucci, G. Contributo dello studio delle anomalie magnetico-gravimetriche regionali alla conoscenza del sottosuolo siciliano. Boll. Com. Geod. Geofis., Milano, Ser. 2, Anno 6, No. 1/2, 1936 (35-43). [Da ùn confronto fra l'andamento delle anomalie regionali magnetiche della Sicilia con quello delle anomalie gravimetriche, ed un altro fra l'andamento delle dette anomalie con quello delle formazioni geologiche

in superficie; come pure dalla distribuzione degli affioramenti vulcanici in Sicilia, vengono discusse le possibili interpretazioni delle anomalie gravimetriche-magnetiche e viene data una idea sulla probabile costituzione del sottosuolo profondo della Sicilia.]

SAN FERNANDO. Anales del Instituto y Observatorio de Marina, publicados de orden de la Superioridad. Sección 1. Observaciones meteorológicas, magnéticas y sísmicas. Año 1935. San Fernando, 1936 (iii+88). 34 cm.

STENZ, E. O przebiegu wiekowym deklinacji magnetycznej w Krakowie. Odbitka z Biul. Tow. Geofiz., Warszawa, zesz. 13, 1936, 13 pp. 24 cm. [Ueber den säkularen Gang der magnetischen Deklination in Krakau. Polnisch mit deutscher Zusammenfassung.]

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B—Terrestrial and Cosmical Electricity

ALBRIGHT, J. G. Apparatus for photographing lightning flashes. Rev. Sci. Instr., Lancaster, Pa., v. 8, No. 1, 1937 (36-37).

ALIVERTI, G. Sugli elementi elettrici del clima in rapporto alla terapia climatica. Boll. Com. Geod. Geofis., Milano, Ser. 2, Anno 6, No. 1/2, 1936 (74-80).

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AUGER, P. Analyse de quelques propriétés des portions dure et molle des rayonnements cosmiques. Berlin, Verlag von Julius Springer, 1936. [Kernphysik, Vorträge gehalten am Physikalischen Institut der Eidgen. Tech. Hochschule Zürich im Sommer 1936, herausgegeben von E. Bretscher, pp. 95-109.]

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HUMPHREYS, W. J. Ball lightning. Philadelphia, Pa., Proc. Amer. Phil. Soc., v. 76, No. 5, 1936 (613-636).

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MILLIKAN, R. A., H. V. NEHER, AND S. K. HAYNES. Precision cosmic-ray measurements up to within a percent or two of the top of the atmosphere. Phys. Rev., Lancaster, Pa., v. 50, No. 11, 1936 (992-998).

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MORGAN, J. E., AND M. W. NIELSEN. Cosmic-ray shower production and absorption in various materials. Phys. Rev., Lancaster, Pa., v. 50, No. 10, 1936 (882-889).

OSLO, NORWEGISCHES METEOROLOGISCHES INSTITUT. Jahrbuch des Norwegischen Meteorologischen Instituts für 1935. Oslo, Gröndahl und Sön, 1936 (155). 33 cm. [Contains values of the electrical potential-gradient and conductivity at the Aas Meteorological Observatory.]

PETRUCCI, G. Una esperienza di laboratorio e una possibile spiegazione della permanenza della carica negativa della Terra. Boll. Com. Geod. Geofis., Milano, Ser. 2, Anno 6, No. 1/2, 1936 (22-34). [Disponendo vicino a un fascio di raggi ionizzanti un conduttore isolato, questo si carica *negativamente*, acquistando potenziali massimi anche dell' ordine di −48 volt. Vengono studiate sperimentalmente le più importanti modalità del fenomeno e si deduce che la carica del conduttore proviene direttamente o indirettamente dai fotoelettroni emessi dall' aria sotto l'azione dei raggi ionizzanti. Si fa vedere, in ultimo, come il fenomeno possa essere preso

in considerazione per tentare di spiegere la carica negativa della Terra e la sua permanenza.]

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Résultats des calculs numériques des trajectoires de corpuscules électriques dans le champ d'un aimant élémentaire. V. Faisceaux de trajectoires avec asymptotes parallèles à l'axe magnétique et normales à cet axe. Oslo, Skr. Vid. Akad., I Mat.-Naturv. Kl., No. 6, 1936, 91 pp. 27 cm.

Remarkable aurora-forms from southern Norway. II. Some arcs and bands with ray structure. Geofys. Pub., Oslo, v. 11, No. 12, 1936 (7 with 10 pls.).

On the trajectories of electric particles in the field of a magnetic dipole with applications to the theory of cosmic radiation. Sixth communication. Astroph. Norvegica, Oslo, v. 2, No. 4, 1937 (193-248).

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Nordlys og natthimmellys, nordlysspektrets variasjoner samt påvisning av typiske forskyvninger i den spektrale intensitetsfordeling der optrer ved solbelyste nordlys. Särtryck, Nordiska (19. skandinaviska) naturforskarmötet i Helsingfors, 1936 (335-337). 25 cm.

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Terrestrial Magnetism
and
Atmospheric Electricity

VOLUME 42 JUNE, 1937 No. 2

THE ELECTRIC CURRENT-SYSTEMS OF MAGNETIC STORMS

By A. H. R. GOLDIE

In "Terrestrial Magnetism and Atmospheric Electricity," Volume 40, No. 4 (December 1935), in a paper under the above title, Professor S. Chapman refers to some work on the same subject by the present writer. Besides replying to certain questions raised by Professor Chapman the writer would like to comment on features of interest and special difficulty.

(1) On page 365 Chapman notes that though his own results and mine[1] are in general agreement and point to maximum currents of the same order, the values given by me for ten of the greatest storms of the year 1926 are about twice as great as those derivable from the storms dealt with in his paper No. 1. Later he remarks that if these ten storms were on the average twice as great as those dealt with in his paper, the difference in results would be natural.

Now these 10 "A" storms, though all selected from the year 1926, were disturbances of very outstanding magnitude. Strictly speaking they were ten storm-days selected from eight magnetic storms. To give some idea of the magnitude of the storms I have selected from the Eskdalemuir records of the years 1916-33 all the storms of magnitude not less than the *least* of these eight storms of the year 1926. The total number obtained from the other 18 years (which included two sunspot-maxima) is only 31. The year 1926 was in fact the most exceptional of the whole period; the other years on the average could each supply only two such storms. The maximum eastward current found from the mean of the ten "A" storm-days was 480,000 amperes, at 17^h local time, nearly overhead or rather to southward of Lerwick (magnetic latitude 63°) and at a mean height of 370 km. The maximum westward current was 595,000 amperes, at 2^h local time, at height 290 km and about 170 km northward of Lerwick. Chapman's current-system for "moderate storm-days" gives maxima of 200,000 eastward and 350,000 westward occurring symmetrically at 18^h and 6^h.

The present writer also dealt with storms of a rather more ordinary category, though still not inconsiderable in magnitude, namely in the 13 "B" storm-days. The maximum easterly current derived from the mean of these was about 400,000 occurring at 18^h at a height of about 270 km and centered some 260 km (or say 2°.5 magnetic latitude) northward of Lerwick; the maximum westward current was rather under 200,000 occurring at 6^h at a height of about 160 km and centered some 200 km northward of Lerwick. It is to be noted too that in these storms

[1]Edinburgh, Trans. R. Soc., 57, Pt. 1, No. 4 (1931).

of lesser magnitude the maximum and minimum currents are practically symmetrically disposed in time.

(2) It is desired to call particular attention to the difference in time and in location of the maximum current in the two classes of storm-days. All the results of the writer for the electric current-system pointed to current-flow deformable according to the magnitude of the magnetic disturbance. The greater the intensity of the disturbance the more does the current-system depart from a symmetrical disposition around the globe, and the more sharply does the general northward flow of current from subtropical regions bend round to become, in or about auroral latitudes, concentrated eastward or westward currents. Thus in very great storms the belt of maximum eastward current lies $0^\circ.5$ or 1° to southward of the latitude of Lerwick and the current is almost perpendicular to the magnetic meridian. In moderate storms the current lies 2° to 3° to northward of Lerwick, the general direction is about east-northeast (magnetic) and the maximum is attained slightly later in the day. Indeed if C be the current and ψ the inclination to the magnetic meridian, the relationship between them was found, from individual cases, to approximate to $C=K \tan \psi$. It is as if the direction of the current were determined by a force proportional to the strength of the current tending to set it, against a resistance, perpendicular to the Earth's magnetic field. Another point is that the greater the disturbance, or the greater the total current, the greater is the proportion of current diverted westward rather than eastward along the auroral zones, that is, the greater the average reduction in H over the globe. It is on the basis of these results and others set out in that paper that the writer inclines to the view that the chief difference, not only between disturbed days of different categories but also between the quiet-day arrangement of electric current and the disturbed-day arrangement of current, is one arising from forces intimately associated with the total amount of current available.

(3) The writer's diagram (Fig. 17) showing the typical disturbed-day electric current-system in northern latitudes has elsewhere been the subject of criticism on the ground that it shows some of the current-lines as ending in auroral latitudes in the time-zone between 20^h and midnight. There would be no point in glossing over the difficulty which here presents itself. In general, in this period between 20^h and 24^h no hypothesis of approximation to a single linear horizontal current leads to any result. Further, taking the day as a whole, all the current which flows into the auroral zone from southward does not again seem to emerge, at least in the same levels. The diagram thus shows simply the results of the calculations based on the magnetic records and does not go beyond them. Birkeland apparently appreciated this difficulty. In the Birkeland-Störmer hypothesis it is covered by the injection into the appropriate part of the Earth's atmosphere of negative electric charge. (The matter in its relation to aurora is dealt with in a later paragraph.)

If the results are correct we may presume the circuits to be completed in other levels, most probably by leakage upward to very great heights and return southwards at such heights. But especially during the late evening and the night the field is undoubtedly complicated by the induced earth-currents to which Chapman has referred. The current represented as emerging from auroral regions in the time-zone from about 20^h to 2^h or later is not unlikely to be greater actually than is portrayed

as having been determined by calculation. Possibly the current here is more diffuse, greater in total amount and some of it at a greater height than the computations based on the simple hypothesis suggested. Obviously some such alternative arrangement could produce, at the Earth's surface, as great magnetic displacements as those observed. But from whatever angle the results are considered it seems that we cannot get away from the explanation that the circuit is completed, in part at least, by some degree of upward penetration of positive current in auroral zones and thence a flow at higher levels from auroral to subtropical latitudes; or, alternatively, by the injection in the auroral zones of negative current.

A few years after the publication of the paper referred to in the above paragraphs, the writer, with the assistance of Dr. D. N. Harrison, made a further investigation to consider magnetic disturbances occurring at times when aurora had definitely been observed. Exactly the same difficulties were found; in every case of aurora present no hypothesis of one simple horizontal linear current could approximately account for the magnetic displacements observed simultaneously at Lerwick and Eskdalemuir. This applied even to cases of quiet auroral arcs, associated with fairly steady displacements of the magnetic components from their normal values.

METEOROLOGICAL OFFICE,
Edinburgh, Scotland, February 12, 1937

NOTES

(See also page 178)

8. *Magnetic survey, United States*—Robert E. Gebhardt has been assigned to take charge of the Sitka Magnetic and Seismological Observatory. He will relieve John Hershberger, who will in turn take charge of the Tucson Magnetic and Seismological Observatory, relieving Dr. James Wallace Joyce, who will be assigned to duty at the Washington Office of the Coast and Geodetic Survey.

Lieut. Comdr. Harold A. Cotton has been assigned to take charge of the San Juan (Puerto Rico) Magnetic and Seismological Observatory, relieving Lieut. Edgar H. Bernstein.

Dr. D. V. Guthrie of the Louisiana State University at Baton Rouge, has with the cooperation of the Coast and Geodetic Survey established a magnetic observatory at which absolute measurements including diurnal variation will be made. This is particularly useful on account of the intermediate position of Baton Rouge between Cheltenham (Maryland) and Tucson (Arizona).

9. *Geophysical Institute at Potsdam*—The official title of the Geophysical Institute of which Prof. J. Bartels is Director, is Geophysikalisches Institut zu Potsdam. It is actually independent of the University of Berlin, the Director only holding a professorship there. The address is "Geophysikalisches Institut, Telegraphenberg, Potsdam, Germany."

10. *Franklin Medalists, 1937*—On May 19, 1937 the Franklin Institute of the State of Pennsylvania, presented Franklin Medals to Dr. *Robert Andrews Millikan*, Director, Norman Bridge Laboratory of Physics and Chairman of the Executive Council of the California Institute of Technology, Pasadena, California; and to Dr. *Peter Joseph Wilhelm Debye*, Director, Kaiser Wilhelm Institute of Physics, Berlin, Germany.

11. *Conference on Cycles, April 23-25, 1937*—A conference on cycles was held April 23, 24, and 25, 1937, by the Carnegie Institution of Washington in the Administration Building of the Institution at Washington, D. C. Its purpose was to bring together various investigators interested in the study of cyclic phenomena and acquaint them with the cyclograph invented by Dr. A. E. Douglass, Research Associate of the Institution.

The morning of the first day was devoted to a discussion of the cycle-problem by Dr. E. B. Wilson of the Harvard School of Public Health and an exposition on the cyclograph and its applications by Dr. Douglass. The afternoon of the first day and all of the second day were devoted to applications of the cyclograph to problems of various branches of science—terrestrial magnetism, variable-star analysis, climatology, tree-ring studies, etc. On the third day the various investigators present discussed the application of cyclic studies in their own particular fields and expounded their individual views regarding the significance of cycles.

In connection with the demonstration of the use of the cyclograph in study of phenomena of other branches of science series of data were furnished Dr. Douglass at the beginning of the Conference by several of the conferees. These data were formed into "cyclograph-plots" by Dr. Douglass' assistant, Mr. Schulman, and examined with the cyclograph. The rapidity with which the cyclic characteristics of these series could be detected by this apparatus stood out in marked contrast to the lengthy and laborious methods necessary to reveal the same characteristics by other methods of analysis.

In addition to Dr. J. C. Merriam, President of the Carnegie Institution of Washington, who opened the Conference, representatives took part from the following organizations: Blue Hill Meteorological Observatory; Brookings Institute; Department of Terrestrial Magnetism, Mount Wilson Observatory, and Geophysical Laboratory of the Carnegie Institution of Washington; Harvard College Observatory; Massachusetts Institute of Technology; Smithsonian Institution; and the Bureau of Agricultural Economics, the Forestry Service, the Soil Conservation Service, and the Weather Bureau of the United States Government.

12. *Corrigenda*—The following changes should be made in the March 1937 number of the JOURNAL: On page 52 in footnote 3 reference should be made to the author's own article, Phys. Rev., **50**, 1189 (1936), in which he notes that the magnetic disturbance accompanying radio fade-outs is of a special type not previously recognized.

The author of the Principal Magnetic Storms at Apia Observatory, appearing on page 413 of the December 1936 issue of this JOURNAL and on page 97 of the March 1937 number, should have been indicated as *W. Ralph Dyer* instead of *H. F. Baird*.

TERRESTRIAL-MAGNETIC AND IONOSPHERIC EFFECTS ASSOCIATED WITH BRIGHT CHROMOSPHERIC ERUPTIONS

By A. G. McNish

Abstract—Magnetic changes occurring at a large number of stations simultaneously with bright chromospheric eruptions reveal that the effect is an augmentation of the normal diurnal variation supposedly due to increased atmospheric ionization by ultraviolet light from the eruption. Radio fade-outs occurring at the same time indicate that this increase of ionization takes place at the base of or below the *E*-layer while the upper layers are unaffected. These facts are adduced in support of the Stewart-Schuster theory which attributes the diurnal variations to dynamo-currents in the ionosphere, since the lower ionosphere is the region in which these currents are likely to flow. The upper regions of the ionosphere are most favorable for the operation of the drift-current and diamagnetic theories. Absence of typical features of magnetic disturbance immediately after and for several days after the more intense eruptions is contrary to the effects predicted by the ultra-violet theory of magnetic storms.

Examination of the processes of ionization indicates that the solar eruptions are adequate causes of the effects observed. These eruptions must produce very large increases in ionizing radiation. It is suggested that normal radiation from the Sun in the extreme ultra-violet is much greater than that calculated on the assumption that the Sun is a black-body radiator at a temperature between 6000° and 7000° K.

Statistical examination of the phenomena suggests that differences in intensity may be adequate explanation for the production of magnetic effects and radio fade-outs by some eruptions, only fade-outs by others, and absence of noticeable terrestrial effects in numerous cases. Fade-outs reported when no eruptions occurred seem attributable to causes of a different nature.

Introduction—Over half a century ago Professor C. A. Young called attention to simultaneous occurrence of brightening of *H*-alpha light in regions of sunspots and certain disturbances of terrestrial magnetism. He surmised that the terrestrial effects were caused by the solar activity and that the active agent connecting the two phenomena was propagated from the Sun to the Earth with the velocity of light. This important observation and suggestion was not considered favorably by other investigators. Students of the Earth's magnetism found that the great perturbations of terrestrial magnetism—called magnetic storms—were related to solar activity in a statistical sense only. Attempts to associate magnetic storms with central-meridian passages of sunspots indicated a lag of a whole day and more between the solar and terrestrial phenomena[1].

A fresh impetus was given this study by Dr. J. H. Dellinger[2] of the National Bureau of Standards who announced that sudden fade-outs of radio signals reflected from the ionosphere had been observed which exhibited an apparent recurrence-tendency of about 54 days—roughly twice the period of solar rotation. At his request, special solar observations were made at the Mount Wilson Observatory of the Carnegie Institution of Washington at times when fade-outs were expected, to ascertain if any visible solar effect could be associated with them. Examination of old spectroheliograms revealed that several of the fade-outs reported by Dr. Dellinger had been accompanied by bright chromospheric eruptions corresponding closely in time.

Further evidence on this apparent connection was supplied by an unusually intense chromospheric eruption[3] revealed on the photographic

[1]W. M. H. Greaves and H. W. Newton, Mon. Not. R. Astr. Soc., **38**, 556-567 (1928); **39**, 84-92 (1928).
[2]Phys. Rev., **48**, 705 (1935).
[3]R. S. Richardson, Terr. Mag., **41**, 197-198 (1936).

plate made at Mount Wilson at $16^h 47^m$ GMT, April 8, 1936. Reports from many radio operators revealed that a wide-spread fade-out of radio signals on the daylight side of the Earth had accompanied this solar outburst, while examination of magnetic records made at Mount Wilson and at Cheltenham, Maryland, disclosed that a sudden change in the Earth's magnetism had taken place at the same time.

Routine observations with the spectrohelioscope were in progress at the Huancayo Observatory of the Carnegie Institution's Department of Terrestrial Magnetism at this time[1]. The observer on duty noticed a remarkable brightening of the *H*-alpha light in the region of a large sunspot, beginning at $16^h 45^m$ GMT. This eruption was accompanied by certain terrestrial phenomena as shown in Figure 1. The spectro-

[1]O. W. Torreson, W. E. Scott, and H. E. Stanton, Terr. Mag., **41**, 199-201 (1936).

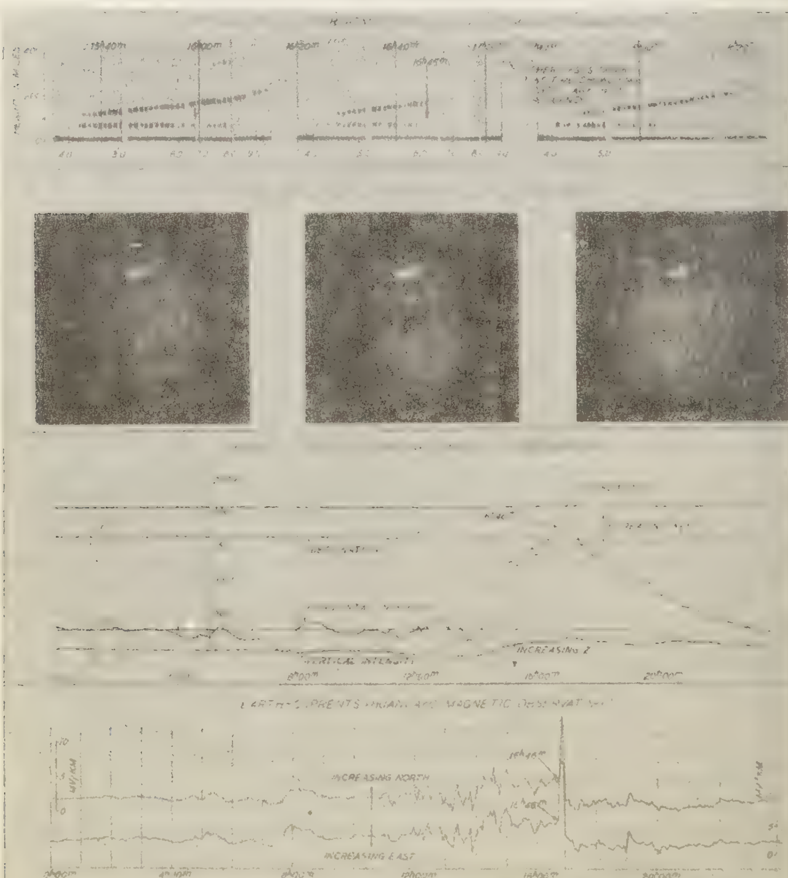


FIG. 1—MAGNETIC, RADIO, AND EARTH CURRENT DISTURBANCES ASSOCIATED WITH BRILLIANT SOLAR ERUPTION, APRIL 8, 1936 (GREENWICH MEAN TIME THROUGHOUT)

heliograms shown in the Figure were made at Mount Wilson before the eruption, while the eruption was at its maximum, and after the eruption had subsided. They show the brightening of the sunspot, although high contrast of the negatives used permits little discrimination regarding intensity. The observers at Huancayo reported that "from the viewpoint of extent and intensity" this was the most spectacular eruption which had been witnessed at the Observatory since beginning routine observations with the spectrohelioscope a year before.

Ignorant of the solar fireworks in progress, the radio operator at the station, who was engaged at the time in making measurements on the ionosphere, found it impossible to receive reflections on any frequency and began to search for defects in his equipment. Finding none, observations were resumed. The disappearance of these echoes and their subsequent return 55 minutes later are illustrated at the top of Figure 1. The sudden changes in the Earth's magnetism and in the earth-currents which are continuously registered at the Observatory are conspicuous in the records at the bottom of the Figure. It may be noted that all the terrestrial effects began at $16^h 46^m$, one minute after brightening became perceptible in the sunspot-region.

This association of events strongly suggests a close relationship between bright chromospheric eruptions and phenomena of the ionosphere and terrestrial magnetism. Extraordinarily bright chromospheric eruptions were observed again on August 25 and on November 6, 1936, and were found to be accompanied by similar phenomena. Although many chromospheric eruptions have been observed during the past few years, a number of which have been accompanied by radio fade-outs, and a still smaller number by magnetic effects[5], the effects accompanying the eruptions of April 8, August 25, and November 6, 1936, have been selected for special study because of the magnitude of the effects involved.

Discussion of magnetic effects—The magnetic effects produced by these bright chromospheric eruptions are distinct in type from any which have been discerned previously. This difference has been inferred[6] and the nature of the special type suggested[7], although the proof of these inferences is possible only by examination of data from a large number of observatories. Examination of the records from a large number of observatories shows that for each observatory affected the change in the magnetic field caused by the chromospheric eruption consisted of an augmentation of the diurnal-variation departure obtaining at that time in each element. The magnitude of this change was roughly proportional to the magnitude of the diurnal-variation departure. The few cases to which this generality is not applicable had negligible diurnal-variation departures at the time of occurrence. Observatories situated more than about 70° from the sub-solar point showed no measurable effects. Changes in vertical intensity caused by the eruptions were small as compared with the changes in horizontal components of the magnetic intensity. This last fact indicates that the portion of the magnetic changes due to causes above and below the surface of the Earth were approximately equal.

Magnitudes and directions for the currents flowing in the ionosphere

[5] J. H. Dellinger, Terr. Mag., **42**, 49-53 (1937).

[6] J. H. Dellinger, Phys. Rev., **50**, 1189 (1936).

[7] J. A. Fleming, Terr. Mag., **41**, 404-406 (1936); A. G. McNish, Nature, **139**, 244 (1937).

which would give rise to the observed magnetic effects have been deduced from the records of a large number of observatories. Such a system is shown in Figure 2 for the effects accompanying the fade-out and eruption of November 6, drawn for the time of maximum magnetic effect.

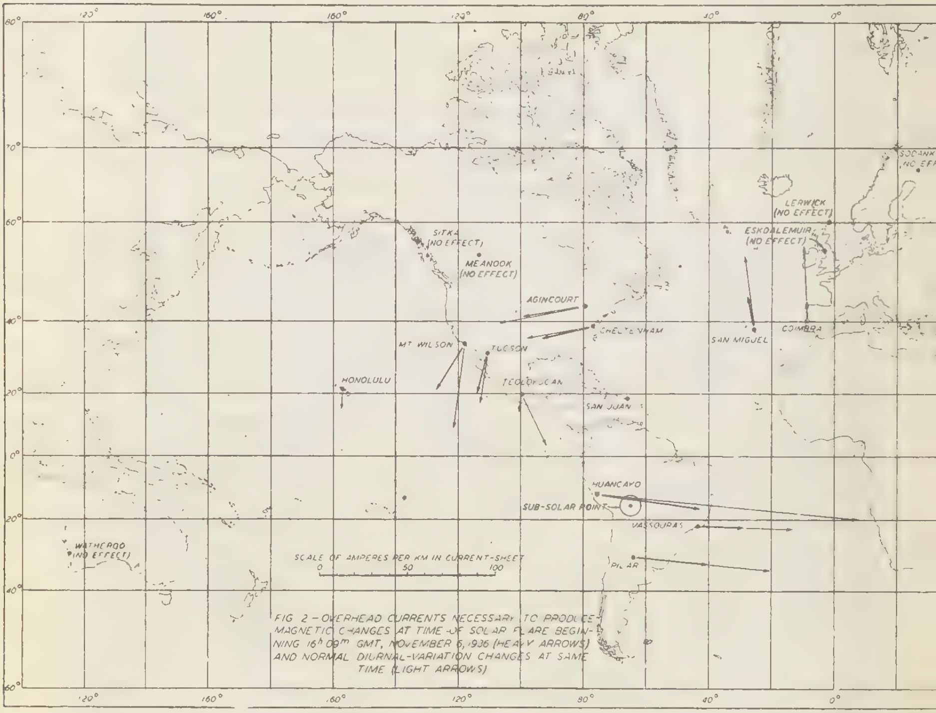


FIG 2—OVERHEAD CURRENTS NECESSARY TO PRODUCE MAGNETIC CHANGES AT TIME OF SOLAR FLARE BEGINNING 16h 09m GMT, NOVEMBER 6, 1936 (HEAVY ARROWS) AND NORMAL DIURNAL-VARIATION CHANGES AT SAME TIME (LIGHT ARROWS)

The heavy arrows show the direction and magnitude of the current of the special disturbance, referred to the interpolated value of the diurnal-variation departure as a zero, while the light arrows represent the diurnal-variation current at the same instant referred to the mean value around the preceding and succeeding midnight as zero. The familiar northern-hemisphere vortex of currents believed to give rise to the diurnal variations is clearly defined by the light arrows. Sufficient data are not available to define the corresponding vortex in the Southern Hemisphere. The current-arrows for the special type of disturbance agree closely with those for the diurnal variation in direction and magnitude. The ratio of the former to the latter decreases with increasing distance from the sub-solar point, the special type of disturbance becoming immeasurably small or *nil* at distances greater than about 70° from the sub-solar point. No arrows are drawn for San Juan as both the special disturbance and the normal diurnal-variation departure were zero. At this particular instant the center of the current-circulation appears to have been directly over the station.

The current-system deduced for the magnetic effects caused by the solar eruption of August 25, 1936 is shown in Figure 3. At this time the sub-solar point was much further north and west, which resulted in appreciable magnetic changes at Meanook, Sitka, and Honolulu and the absence of discernible effects at San Miguel and Coimbra. In this case

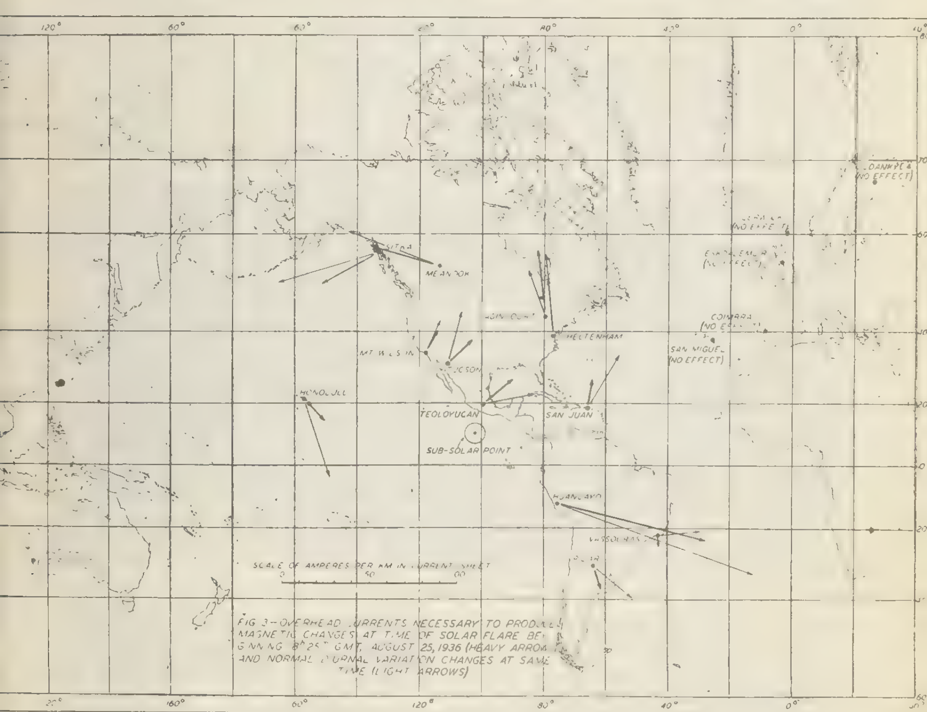


FIG 3—OVERHEAD CURRENTS NECESSARY TO PRODUCE MAGNETIC CHANGES AT TIME OF SOLAR FLARE BEGINNING 8h25m GMT, AUGUST 25, 1936 (HEAVY ARROWS) AND NORMAL DIURNAL VARIATION CHANGES AT SAME TIME (LIGHT ARROWS)

the currents in the Southern Hemisphere were less intense than they were for November 6, but the southward components of the currents over Vassouras and Pilar indicate the current-vortex of the Southern Hemisphere while that of the Northern Hemisphere is clearly defined.

The current-system deduced for the effects occurring on April 8 is portrayed in Figure 4. Particular interest is attached to the apparently anomalous direction of the arrows for Teoloyucan. The configuration indicated by the arrows at other points suggests that the arrows for Teoloyucan should point in the same direction as those for Tucson and Mt. Wilson, and that the change from a southwest to a northeast direction should occur close to San Juan. The fact that the diurnal-variation arrow also exhibits the anomaly displayed by the arrow for the special disturbance clearly indicates that the current-system of the special disturbance is an augmentation of the normal diurnal-variation current – not a unique system of its own which only simulates the normal diurnal-variation system. On this particular day the variation in declination

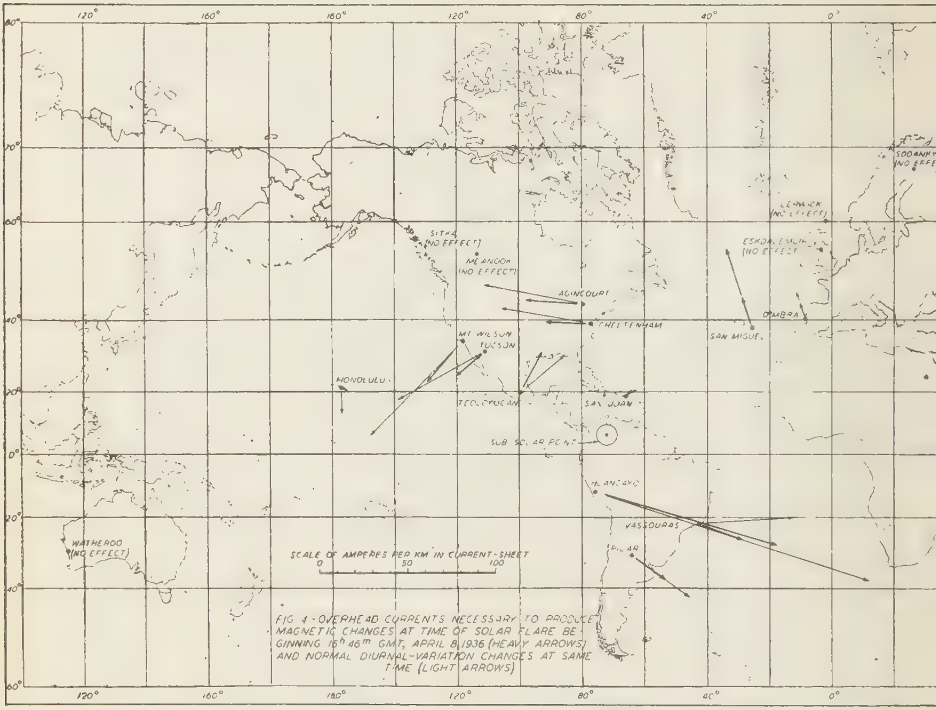


FIG 4 - OVERHEAD CURRENTS NECESSARY TO PRODUCE MAGNETIC CHANGES AT TIME OF SOLAR FLARE BEGINNING $16^h 46^m$ GMT, APRIL 8, 1936 (HEAVY ARROWS) AND NORMAL DIURNAL-VARIATION CHANGES AT SAME TIME (LIGHT ARROWS)

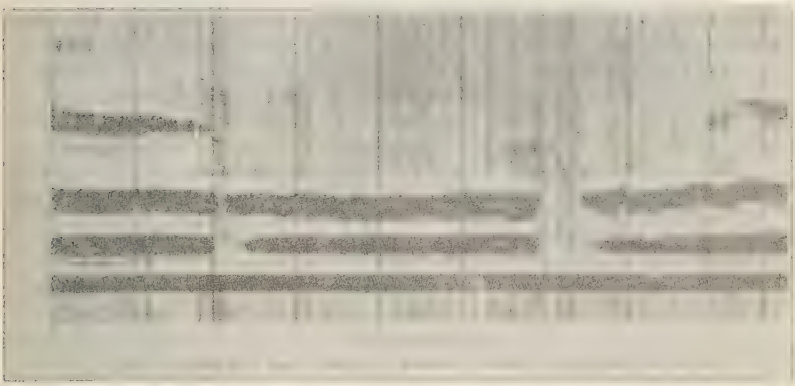
at Teoloyucan exhibited an eastward swing which persisted all day instead of the usual double swing, first to the east and then to the west. Such anomalous features of the normal diurnal variation have been noticed previously and studied[8].

The conclusions which may be drawn from the magnetic and ionospheric effects caused by bright chromospheric eruptions are of fundamental importance to theories of terrestrial-magnetic variations and of the ionosphere. The close agreement in time of the various effects, particularly those of April 8 for which the exact time of beginning of the solar flare is available, clearly indicates that the active agent is transmitted from the Sun to the Earth with about the velocity of light. In this case brightening of the H-alpha light in the region of a sunspot began at $16^h 45^m$ GMT, sudden changes in the Earth's magnetism and in the earth-currents occurred one minute later—at $16^h 46^m$ GMT—and at the same time fade-out of high-frequency radio reflections occurred. The slight time-interval of one minute between the first observation of brightening and incipience of noticeable terrestrial effects does not necessarily imply that the active agent travelled less rapidly than the visible light. Such a lag is expected since the terrestrial effects must be of an accumulative nature—time is required for them to become perceptible. Confinement of the effects to the daylight portion of the Earth is definite

[8]V. Vacquier, Terr. Mag., **42**, 17-28 (1937).

evidence of rectilinear propagation and hence corroborates the assumption that the agent is light-radiation.

Discussion of radio effects—The fade-outs affected all radio frequencies which are ordinarily reflected from the E-, F_1-, and F_2-regions. Subsequent reappearance of reflections from these regions about an hour after the fade-out occurred reveals that these layers had undergone no appreciable change in height or ion-density. This is unambiguous evidence that the fade-out must have been due to formation of an absorbing layer at the base of or below the E-layer. A clear demonstration of these facts is supplied by Figure 5 showing a record of continuous reflections at a frequency of 4800 kc/sec on May 28, 1936, when two fade-outs occurred.



Both of these fade-outs are undoubtedly of the same nature as those discussed previously. No solar observations are available at the time of their occurrence, although a photograph of the Sun made at $14^h\,38^m$ GMT—38 minutes after the first fade-out—revealed a chromospheric eruption in one sunspot-group. The second fade-out was accompanied by slight terrestrial-magnetic effects. The lower solid line in the Figure is the ground-wave or base-line, the line above is a border-reflection from the E-layer, while the line above that is the F_1-layer reflection. The higher lines which appear only at the edges of the record are multiple reflections from the F_1-layer. In both cases the weak border-reflections from the E-layer were affected for a longer time than the stronger reflections from the F_1-layer. This further supports the view that the fade-outs are due to absorption in a lower region. Such effects would result from dense ionization at low heights where collisional frequency is comparable with the frequency of the radio waves.

Further evidence upon this point is supplied by the findings of Bureau[9] who reports increases in low-frequency atmospherics at times of fade-outs on high frequencies. These atmospherics which correspond to frequencies of about 27 kc sec, he believes, come in more strongly at times of fade-outs of high frequencies through improved quality of the lower portion of the ionosphere as a reflector of low frequencies. The

[9] R. Bureau, Nature, 139, 110-111 (1937).

low frequencies are transmitted by this low layer in spite of the high collisional frequency because, owing to great ionization there, the layer behaves much like a metallic reflector.

Thus all the evidence supplied by the radio data is reconcilable with a single explanation—the formation of dense ionization at the base of or below the E-region while the upper layers are substantially unaffected. It has been shown previously that the magnetic effects associated with these fade-outs consist of a sudden augmentation of the normal diurnal variation. The conclusion follows that the normal diurnal variations of terrestrial magnetism arise largely or entirely in these lower regions of the ionosphere and do not depend upon processes occurring at great heights.

Relation of effects to theories of magnetic variations—The Stewart-Schuster theory attributes the diurnal variations of terrestrial magnetism to electric currents flowing in a conducting atmosphere, impelled by certain electromotive forces. These electromotive forces are conceived of as due to horizontal tidal motions of the atmosphere across the vertical component of the Earth's permanent magnetic field. They would undoubtedly be affected by local winds at great heights, accounting for local distortions in an idealized pattern of the electric circulation. Owing to the anisotropic conductivity of an ionized gas in the presence of a magnetic field[10] the direct-current conductivity of the ionosphere in directions perpendicular to the magnetic field can be appreciable only where the collisional frequency of the electrical carriers is comparable with or greater than their gyromagnetic frequency. These considerations of electric conductivity indicate that if the magnetic variations arise through the mechanism outlined by the Stewart-Schuster theory the currents flow in the lower region of the ionosphere.

These difficulties of the Stewart-Schuster theory caused the proposal of the diamagnetic[10] and the drift-current[11] theories to explain the magnetic variations. Both theories depend upon the behavior of the ionized regions at very great heights where very large numbers of ions and electrons exist and where their collisional frequency is low as compared with their gyromagnetic frequencies.

Definite proof that the magnetic diurnal variations arise in the lower part of the ionosphere rather than in the upper would permit some discrimination between the Stewart-Schuster theory and the diamagnetic or drift-current theories. Exactly such evidence appears to be offered by the facts presented here and it is unequivocally in favor of the Stewart-Schuster theory.

In accordance with this theory the electromotive forces to impel the currents exist at all times. The sudden ionization caused by the chromospheric eruption permits a sudden increase in the currents then flowing. Local anomalies of the normal diurnal variation which appear to be so faithfully reproduced by the special disturbance thus do not seem to arise from irregularities in ionization but from irregularities in the distribution of electromotive forces and hence, ionospheric winds.

An interesting feature is brought out by the rapidity with which the augmentation of the diurnal variation takes place. During the fade-out of April 8 horizontal intensity at Huancayo attained its maximum value

[10]R. Gunn, Phys. Rev., 32, 133-141 (1928).
[11]S. Chapman, Proc. R. Soc., A, 122, 369-386 (1929).

at $16^h\ 50^m$ GMT, five minutes after brightening began and four minutes after onset of the increase in magnetic intensity. This maximum in magnetic force appears to have occurred at about the time of maximum intensity of visible light from the eruption. Return to normal conditions occurred with comparable rapidity and appeared to coincide closely with diminution of brightness. In view of the great dimensions of the electric circuit as compared with the rapidity of the changes it appears that the reactance of the circuit is negligible. Such a condition can arise from the induction of currents in the Earth almost equal in magnitude to the currents in the external circuit and so directed that the component of magnetic flux perpendicular to the Earth's surface produced by the internal circuit opposes that of the external circuit. This view is evidenced by the fact that changes in the vertical component of the magnetic field were quite small at all observatories. Application of the same consideration to the Stewart-Schuster theory of the diurnal variations might assist in bringing the theoretical phase-angles of the several harmonics into better agreement with the observed phase-angles.

The magnetic phenomena accompanying these chromospheric eruptions also furnish a test of the ultra-violet light theory of magnetic storms[12]. There can be no doubt that the visible light produced by an eruption is accompanied by ultra-violet light capable of ionizing the gases of the ionosphere. Since all three of the eruptions discussed in this

[12] H. B. Maris and E. O. Hulburt, Phys. Rev., **33**, 412-431 (1929); E. O. Hulburt, Phys. Rev., **34**, 344-351 (1929).

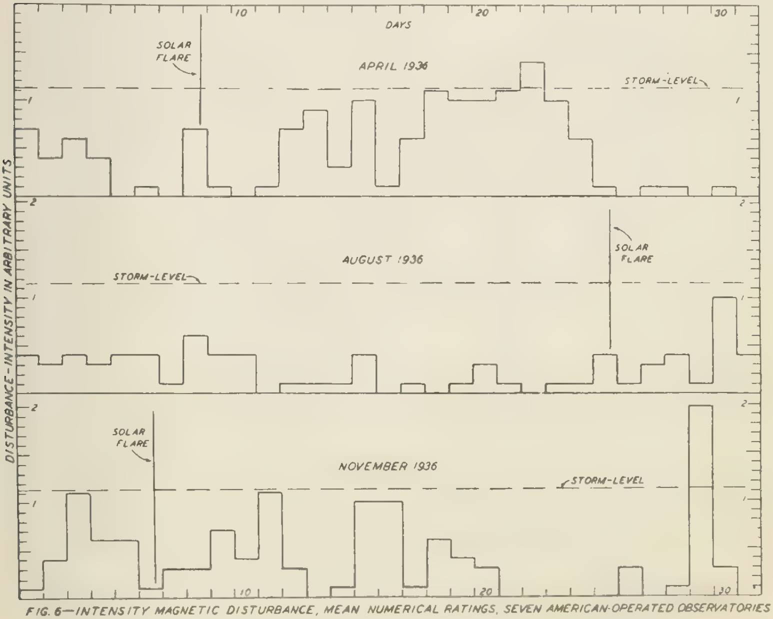


FIG. 6—INTENSITY MAGNETIC DISTURBANCE, MEAN NUMERICAL RATINGS, SEVEN AMERICAN-OPERATED OBSERVATORIES

paper produced strong ionization they should have produced magnetic storms, in accordance with the theory. On the contrary, the evidence clearly shows that no magnetic storms followed any one of these eruptions within an interval of several days, as is revealed by Figure 6.

The type of magnetic disturbance resulting from these eruptions is of very special character, quite distinct from the type of disturbance occurring during or at the beginning of a magnetic storm. The system of ionospheric currents necessary to produce a bay-disturbance—a common feature of magnetic storms—is shown in Figure 7. The differences between this world-wide circulation and the well-defined and restricted circulations shown in Figures 2, 3, and 4 are obvious. Magnetic storms are most strongly manifested in polar regions while the special disturbances accompanying a chromospheric eruption are most strongly manifested in low and middle latitudes. This evidence does not preclude the possibility that some other type of ultra-violet radiation may produce different effects from those noted here, although this view is not alluring.

Processes of ionization and recombination—Meagerness of data on the nature of light-emission from these chromospheric eruptions and on the physical state of the ionosphere renders speculation regarding the ionic processes involved extremely hazardous. Spectrograms over a narrow range, taken at Mt. Wilson, indicate that little or no increase

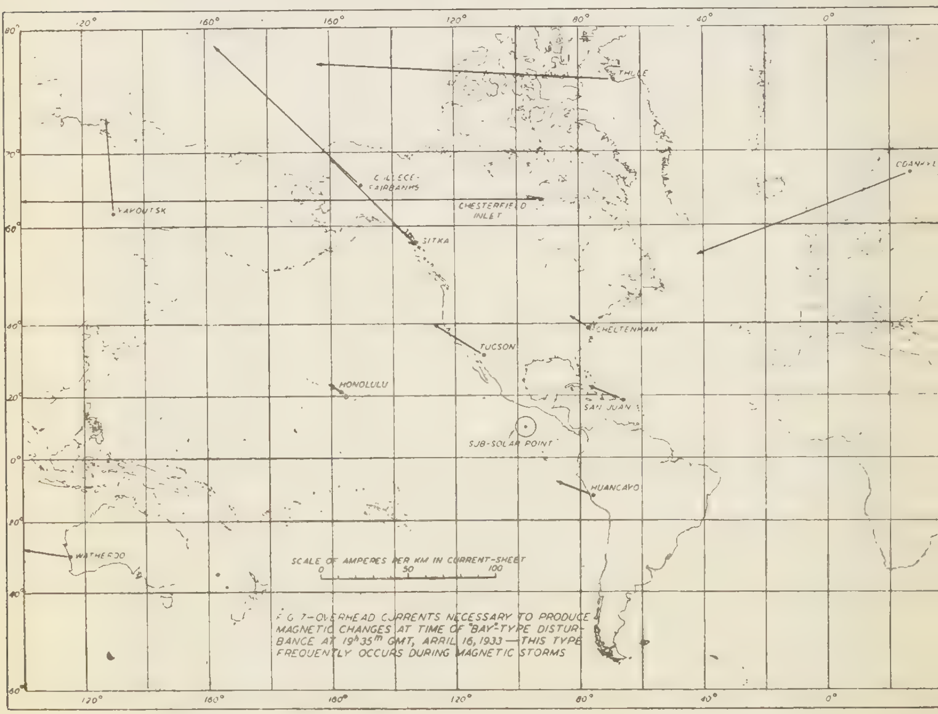


FIG. 7—OVERHEAD CURRENTS NECESSARY TO PRODUCE MAGNETIC CHANGES AT TIME OF "BAY"-TYPE DISTURBANCE AT 19h35m GMT, APRIL 16, 1933—THIS TYPE FREQUENTLY OCCURS DURING MAGNETIC STORMS

in black-body radiation accompanies an eruption. The gases which emit the radiation are thrown to great heights in the solar atmosphere so that much of the light emitted escapes into space. Although hydrogen is responsible for most of the emission, photographs of the phenomena have been obtained in the H- and K-lines of calcium as well. During the more intense outbursts the alpha-line of hydrogen—ordinarily a dark line—reaches an intensity in the eruptive region considerably greater than the intensity of the Sun's disc in the surrounding part of the spectrum.

Since gas-pressures are exceedingly low in the solar atmosphere, excitation of many of the lines of the Balmer series is probable. Corresponding emissions in the Lyman series are to be expected which would produce ionizing radiations of considerably greater intensity than are emitted from equal black-body areas at the effective solar temperature. Ultra-violet radiations from other elements of the chromosphere undoubtedly occur also, although their intensity may be very much less than the hydrogen-emissions. The ionizing radiations responsible for the terrestrial effects probably originate in this manner.

To account for the terrestrial phenomena the large increase in ionization at low heights in the ionosphere without any appreciable change at great heights must be explained. Present evidence indicates that ionization in the E- and F_1-regions is due largely or exclusively to ultra-violet light[13], yet the light from the chromospheric eruptions appears to penetrate these regions without producing any noticeable effects although it is capable of producing ionization at the base of or below the E-region. Several possibilities are recognized.

Ultra-violet radiation from the chromospheric eruptions may be less strongly absorbed than the normal ultra-violet radiation from the Sun, thus permitting it to penetrate more deeply into the atmosphere, or, in addition, the radiations from the eruptions may encounter a new constituent of the atmosphere at the heights at which this ionization is produced. A suggestion along these lines has been made to the writer by Dr. O. R. Wulf of the Bureau of Chemistry and Soils, Department of Agriculture, who called attention to the comparative transparency of the atmosphere in the region between 1100 and 1300 Ångstroms—the beginning of the Lyman series. These wave-lengths could penetrate to the lower part of the E-region where ozone—a possible constituent of the atmosphere at such heights—might become ionized by them. Since this is the height at which oxygen-molecules first become appreciable they might be responsible for the effects as molecular oxygen absorbs strongly in the shorter wave-lengths of the Lyman series and its continuum.

While this last suggestion is particularly pregnant, the effects may be explained in another way which involves no assumptions concerning the composition of the chromospheric radiation or the distribution of the constituents of the atmosphere. Ionization is probably always present during daylight hours at the base of or below the E-layer of sufficient density to absorb radio waves in the broadcast band, although this ionization is insufficient to absorb the higher frequencies. Owing to higher rates of recombination ionic densities in this region are suppressed below

[13]S. S. Kirby, L. V. Berkner, T. R. Gilliland, and K. A. Norton, Bur. Stan. J. Res., **11**, 829-845 (1933).

those obtaining in the higher layers. The quantity of ionizing radiation absorbed in this layer may considerably exceed that absorbed in the higher layers, the ion-density being determined by the expression $\sqrt{q/\alpha}$, where q is the rate of ion-production and α is the recombination-coefficient.

If the intensity of the incoming radiation is suddenly increased the rate of ion-production will be increased proportionally in all layers. However, the ionization of the lower layers will increase most rapidly and may approach quite close to its equilibrium-value before the increases in the upper layers become perceptible. With decrease in ionizing radiation from the eruption ion-density will decrease in all layers, so that when the lowest layer ceases to absorb high-frequency radio waves the upper layers will reappear in substantially their original condition. The ratio of ions to electrons in this lower absorbing layer is likely to be high.

The rapidity with which the ionization decreases in this lower layer bespeaks a rapid rate of recombination. In order to maintain a background ionization at this level sufficient to absorb waves in the broadcast band the rate of ion-formation must be quite high. This suggests that the extreme ultra-violet radiation coming from the Sun may be much more intense than that which would be produced if the Sun were a black-body radiator at a temperature between 6000° and 7000° K. During the chromospheric eruptions discussed in this paper this ionizing radiation increased by a factor of four or more, judging from the magnitude of the magnetic effects.

Statistical features of phenomena—Many chromospheric eruptions have been observed which were not accompanied by radio fade-outs or magnetic changes, and a number of radio fade-outs have been reported which were not accompanied by visible chromospheric eruptions, although H-alpha spectroheliograms were taken at the time at the Mt. Wilson Observatory. An explanation of these facts must be sought.

The occurrence of fade-outs accompanied by no reported solar eruptions is due in part to the absence of solar observations at the time of occurrence. However, several radio fade-outs have been reported by Dellinger[14] which were not accompanied by visible eruptions although spectroheliograms had been taken shortly before and shortly after the fade-out time. Since fade-outs were included in Dellinger's list if reported by only two observers it is likely that some phenomena reported as fade-outs are of a different nature; that is, they may be due to some variation in ionospheric conditions other than creation of a low absorbing layer. If a station is working close to the critical frequency of penetration a decrease in ion-density may result in interrupted communication which might be interpreted as a fade-out. It is important to note that visible solar eruptions were observed at the time of 17 of the 23 more intense fade-outs (indicated by asterisk in Dellinger's list)[15]; there is no evidence to show that the remaining eight cases were not accompanied by visible eruptions. The occurrence of solar eruptions releasing ultra-violet light without visible radiation is a conceivable explanation for

[14] Terr. Mag., **42**, 49-53 (1937).

[15] Fade-outs occurring at 14^h 24^m, 15^h 55^m, and 17^h 50^m GMT, June 9, at 20^h 55^m GMT, June 10, and at 18^h 00^m GMT, June 16 were also accompanied by visible eruptions although this is not indicated in the list.

fade-outs unaccompanied by visible eruptions, but this view is less satisfactory than the one which has been offered.

To explain the occurrence of chromospheric eruptions which are not accompanied by radio fade-outs or magnetic effects Dellinger [14] has stated that some visible eruptions are accompanied by ionizing radiations and some are not. Richardson[16] examined eruptions which caused fade-outs and compared them with eruptions for which no fade-outs had been reported and could detect no noticeable difference between the two except that those which caused fade-outs were much brighter than those which did not. A list of chromospheric eruptions observed at Mt. Wilson since April 1934 giving estimates of intensity on a scale 1, 2, 3 has been supplied to the writer by Dr. R. S. Richardson of the Mt. Wilson Observatory of the Carnegie Institution of Washington. All the eruptions of intensity 3 contained in this list were accompanied by radio fade-outs. The eruptions causing the magnetic effects described earlier in this paper were designated as intensity 3, except that of November 6 which was estimated as intensity 1 or 2 a considerable time after its beginning. Had observations been made earlier it would undoubtedly have been designated as intensity 3. These figures on intensity are only visual estimates and do not take into account the areas of the regions involved, and therefore do not constitute an accurate indication of the quantity of radiation proceeding from the eruption.

Observation of radio fade-outs depends upon several factors. Weak reflections may be absorbed while strong reflections are returned, as demonstrated by Figure 5. Signals transmitted and received at large angles of incidence are more likely to be absorbed than if the angles of incidence are small, owing to the former having to pass through more of the absorbing layer. Whether or not a fade-out is reported may depend, in a number of cases, upon the power of the transmitting station and the path taken by the wave. For this reason ionospheric measurements made at vertical incidence furnish the best records of these phenomena[17].

The ability of an eruption to produce a radio fade-out or a magnetic effect does not seem to depend upon its position on the Sun's disc. The strong effects of August 25 were produced by an eruption occurring 0.96 of the solar radius from the center of the disc, while fade-outs appear to have been produced by eruptions occurring on the limb of the Sun. This independence of position may be attributed to the heights to which the emitting gases are thrown, which permits radiation from them to proceed into space without appreciable absorption in the solar atmosphere.

Production of terrestrial effects by chromospheric eruptions apparently depends upon the intensity of the eruption and the area of the region affected. Provisionally one may state that the most intense and largest eruptions produce both fade-outs and magnetic effects, smaller and less intense eruptions cause only fade-outs, while the least intense but more numerous eruptions produce no noticeable effects on the Earth. Definite conclusion on this matter must await measurement of relative intensity of the various spectral lines present and a less subjective estimate of the intensity of individual lines.

[16]Pub. Astr., Soc. Pacific, **49**, 82-86 (1937).

[17]L. V. Berkner and H. W. Wel s, Terr. Mag., **42**, 183-196 (1937).

Acknowledgment—The writer expresses his indebtedness to the numerous individuals and organizations for the excellent magnetic data which have permitted delineation of the special magnetic-disturbance system, particularly to Dr. R. S. Richardson and Dr. S. B. Nicholson of the Mt. Wilson Observatory of the Carnegie Institution of Washington, who also supplied data concerning the chromospheric eruptions. In prosecution of this investigation it was the writer's privilege to discuss the phenomena freely with his colleagues, particularly L. V. Berkner of the Department of Terrestrial Magnetism, and Dr. Richardson and Dr. Nicholson, whose opinions on various matters have aided considerably. Acknowledgment for his encouragement and whole-hearted support is due Dr. J. A. Fleming, Director of the Department of Terrestrial Magnetism, whose efforts in behalf of a spectrohelioscopic program at the Huancayo Magnetic Observatory resulted in the inception of this investigation.

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
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OUR KNOWLEDGE OF THE LUNAR-DIURNAL VARIATION OF THE MAGNETIC DECLINATION AND NEW RESULTS OBTAINED FROM OBSERVATIONS AT MOGADISCIO

By M. Bossolasco and J. Egedal

The opinion that the magnetic diurnal variations also depend on the magnetic elements in the place where they have been recorded, has been set forth by Ad. Schmidt[1]; thereafter the question has been treated occasionally, most recently in a paper by A. G. McNish[2]

For this question the magnetic observations made during the Polar Year at Mogadiscio are of special interest because the magnetic observatory there lay in the *northern* geographic but in the *southern* magnetic hemisphere, in other words, the Observatory lay between the geographic and the magnetic equators[3].

In order to examine the above question the lunar-diurnal variation of the declination at Mogadiscio was determined; the variation of the lunar effect at the different hours of the solar day was also examined.

Observational data—The geographic coordinates of the Mogadiscio Magnetic Observatory are: $\phi=2°\ 02'.0$ north, $\lambda=45°\ 21'.3$ east. The geomagnetic latitude of the station is 2° 43′ south and the magnetic inclination is 16°.5 south.

During August 1, 1932, to July 31, 1933, instantaneous values of the declination are ready for use but only the values from August 1, 1932, to July 22, 1933 (12 lunations), were used for the present work.

Derivation of the variations—For the derivation of the lunar-diurnal variation, observations from each lunation were treated separately. Values for the solar hours were used. They were arranged in a list so that the value of the solar hour nearest to the lower culmination of the Moon was placed in the first row of the list and thereafter the values of the following hours were placed one after the other in the following rows. Then the departures from the mean for the solar hours during the lunar day were found. By interpolation the departures for the lunar hours were computed; in order to find the lunar-diurnal variation the reduction in amplitude arising from the use of values for solar hours and the interpolation mentioned had to be corrected. The *facteur d'augmentation* determined was 1.033. The derivation of the lunar variation for different solar hours was made in a similar manner, and the *facteur d'augmentation* found was 1.032.

Reckoning declination positive towards the east, the values for the main term (L_2) of the lunar-diurnal variation in declination at Mogadiscio are given in Table 1.

The standard deviations of the amplitudes found are of the order of magnitude 0′.05, for the four months, November to February, and the standard deviations are ±0′.038, ±0′.059, ±0′.054, and ±0′.047, respectively. The standard deviations of the phase-angles for the four above-mentioned months do not exceed 13° or 52^m.

[1]Physik. Zs., **19**, 349-355 (1918).

[2]Terr. Mag., **40**, 151-158 (1935).

[3]Compare Resolution 10*a*, of the Polar Year Commission at Copenhagen 1933, Terr. Mag., **38**, 244 (1933), and J. Egedal, Terr. Mag., **36**, 139-140 (1931).

Table 1—*Lunar-diurnal variation in declination at Mogadiscio, 12-hour term,* $L_2 = A \sin (2t+b)$

Dates	Amplitude (A)	Phase-angle (b)	Dates	Amplitude (A)	Phase-angle (b)
1932-1933	′	°	*1933*		°
Aug 1 to Aug 31	0.03	88	Jan 25 to Feb 24	0.41	99
Aug 31 to Sep 30	0.32	14	Feb 24 to Mar 25	0.29	98
Sep 20 to Oct 29	0.28	24	Mar 25 to Apr 24	0.19	73
Oct 29 to Nov 27	0.24	99	Apr 24 to May 24	0.13	264
Nov 27 to Dec 27	0.29	94	May 24 to Jun 23	0.03	294
Dec 27 to Jan 25	0.25	104	Jun 23 to Jul 22	0.08	270

The values of Table 1 are represented in the harmonic dial, Figure 1. In Figure 1 the measure of the amplitudes is indicated on the axis, and the measure of the times of the occurrence of the maximum in relation to the culmination of the Moon is indicated at the axis. For each month

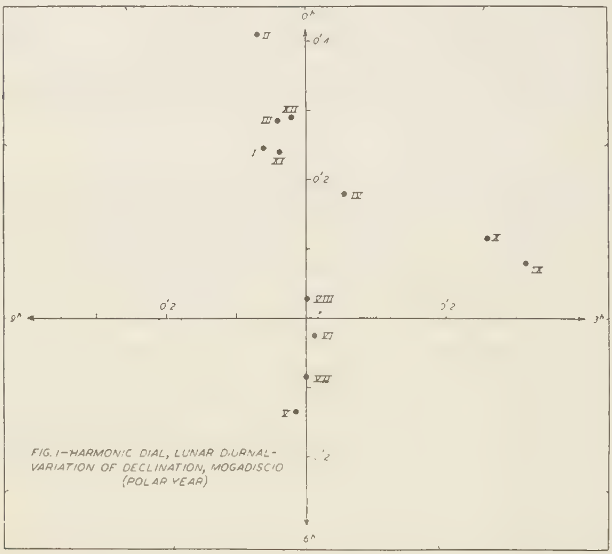

FIG. 1—HARMONIC DIAL, LUNAR DIURNAL-VARIATION OF DECLINATION, MOGADISCIO (POLAR YEAR)

(indicated by its number) the lunar-diurnal variation is represented by a dot in the Figure.

For the main term (L_2) of the lunar variations during northern winter for different hours of the day the values shown in Table 2 were derived.

Discussion—The lunar-diurnal variation (Table 1 and Figure 1) shows an amplitude of nearly 0′.3 (3γ) for the months of the northern winter, but for the months of the northern summer the amplitude is considerably smaller. The phase-angle is fairly constant for northern winter—

TABLE 2—*Lunar-diurnal variation in declination at Mogadiscio, 12-hour term, $L_2 = A \sin (2t+b)$, for different solar hours, northern winter*

Solar time 45° EMT	Amplitude (*A*)	Phase-angle (*b*)	Solar time 45° EMT	Amplitude (*A*)	Phase-angle (*b*)
h	′	°	*h*	′	°
6	0.51	38	13	0.40	106
7	0.61	37	14	0.61	128
8	0.40	44	15	0.58	105
9	0.28	80	16	0.54	94
10	0.64	99	17	0.20	78
11	0.85	84	18	0.07	87
12	0.61	89	19 to 5*	0.11	85

*Northern summer. During northern summer the amplitudes and phase-angle of the term L_2 were 0′.18 and 314°, respectively, for the solar hours 6 to 17.

about 90°; for northern summer the phase-angle is uncertain but values differing about 180° from values in northern winter values dominate.

It will be seen that for northern summer the variations seem to have a phase-angle nearly equal to those of other magnetic observatories in the Northern Hemisphere. But it should be added that more data are necessary in order to determine the phase-angle with certainty.

On account of the geographic position of the Observatory at Mogadiscio the seasons used above are those of the Northern Hemisphere, but both the lunar-diurnal and the solar-diurnal[4] variation at Mogadiscio are of the same type as the corresponding variations in the Southern Hemisphere.

Until now all phase-angles of L_2 determined from records obtained from magnetic observatories lying in the Northern Hemisphere have been found to be about 270°, but in the case of Mogadiscio, for the first time, a phase-angle of about 90° is found for that part of the year where the lunar-diurnal variation is greatest.

Formerly functions of geographic coordinates have been used for the representation of the field of the lunar-diurnal variation, and it has been assumed that the variation is nearly the same for all magnetic observatories lying in the same geographic latitude. The above-mentioned results, according to which the phase-angle found for Mogadiscio differs by 180° from the phase-angles obtained from observations at other observatories in the Northern Hemisphere, show that the assumption hitherto used does not agree with the results obtained for Mogadiscio, and therefore it might possibly be useful to represent the field as a function depending on the magnetic elements of the place of observation.

In the present case a relatively great amplitude of L_2 was found in a place where the geomagnetic latitude is rather small, and therefore functions of geomagnetic coordinates do not seem useful for the representation of the field under consideration. Perhaps functions of the magnetic inclination would be more suitable.

Regarding the theories of magnetic diurnal-variations it hitherto has not been possible to make a deciding and complete comparison between

[4]M. Bossolasco: Il magnetismo terrestre alla luce delle osservazioni fatte durante l'Anno Polare Internazionale 1932-33, Atti Soc. Ital. Prog. Sci., XXIV Riunione, Palermo 1935, 2, Pavia 1935.

theory and observations as far as lunar-diurnal variation is concerned, because sufficient data have not been available. On account of the distribution of the magnetic observatories the available magnetic data made it evident that the amplitude of the lunar-diurnal variation of the declination should be near to zero at the geographic equator, but, contrary to expectations, the present data from Mogadiscio, lying near the equator, show a very great amplitude for the northern winter.

In using data derived by S. Chapman, J. Bartels[5] found that the atmospheric electric current-system—giving a variation equal to that of the lunar-diurnal variation—for the summer hemisphere also extends into the opposite hemisphere. This result may offer an explanation of the great amplitude found for Mogadiscio in northern winter, but on account of the position of the Observatory near the equator one should expect amplitudes of the lunar-diurnal variation for the summer season just as great as those of the winter season. This is not the case, but possibly a representation of the field based on both geographic coordinates and coordinates depending on the magnetic elements of the place of observation would lead to a more harmonious result.

The lunar variations for the different hours of the solar day (Table 2) show amplitudes greater than half the maximum values for the greater part of the day (about ten hours). For Batavia[6] the duration for the declination of the above-mentioned period is seven hours, which agrees with the variation of the electrical conductivity of the air given by S. Chapman[7] in the form $[1+(3/2)\cos\omega]^2$. This formula represents a variation having its maximum at noon, but the maximum of the amplitudes for Mogadiscio, as well as for Batavia, occurs one or two hours before noon.

From Table 2 it will be seen that the amplitudes for the day-hours for northern winter are about five times greater than for all the night-hours. For northern summer the amplitude for all the hours of the day is rather small.

Summary—For the best representation of the field of the lunar-diurnal variation coordinates depending also on the magnetic elements of the place of observation should be used. Until now it has not been possible to compare theories on lunar-diurnal magnetic variation with the observations in a complete manner, because data have not been sufficient; in the future the data from Mogadiscio (and Pará) will make knowledge of the variation in question more complete.

In conclusion we thank Professor J. Bartels for his valuable suggestions and the interest he has shown in the work, and V. Laursen for his kind assistance.

[5]Elektr. Nachr.-Technik, **10**, Sonderheft (1933).

[6]Batavia, Obsns. Mag. Met., Appendix, 1903.

[7]Phil. Trans. R. Soc., A, **218**, 57 (1918).

MAGNETIC SECULAR CHANGE IN SWEDEN, 1929-1936

By Gustaf S. Ljungdahl

Abstract—Preliminary values of the average secular change of declination, inclination, and horizontal intensity from 46 remeasured field-stations are given as functions of geographical latitude and longitude.

In the years 1928-30 the Hydrographic Service of Sweden established a net of magnetic stations over the whole country, intended to serve as main repeat-stations[1]. In 1936, 51 of these field-stations were remeasured, and during 1937 this resurvey will be completed.

Each station was carefully marked during the first survey, and therefore in 1936 it was possible to reoccupy exactly the same places. Five of the measured, highly disturbed stations, however, have been excluded in the following, and the number of stations used is 47, including the Lovö Observatory. The distribution of the field-stations is shown on the chart of Figure 1.

[1]G. Ljungdahl, A magnetic survey of Sweden made by the Hydrographic Service in the years 1928-1930, Stockholm, Kungl. Sjökarteverket, Jordmag. Pub. Nr. 9 (1934).

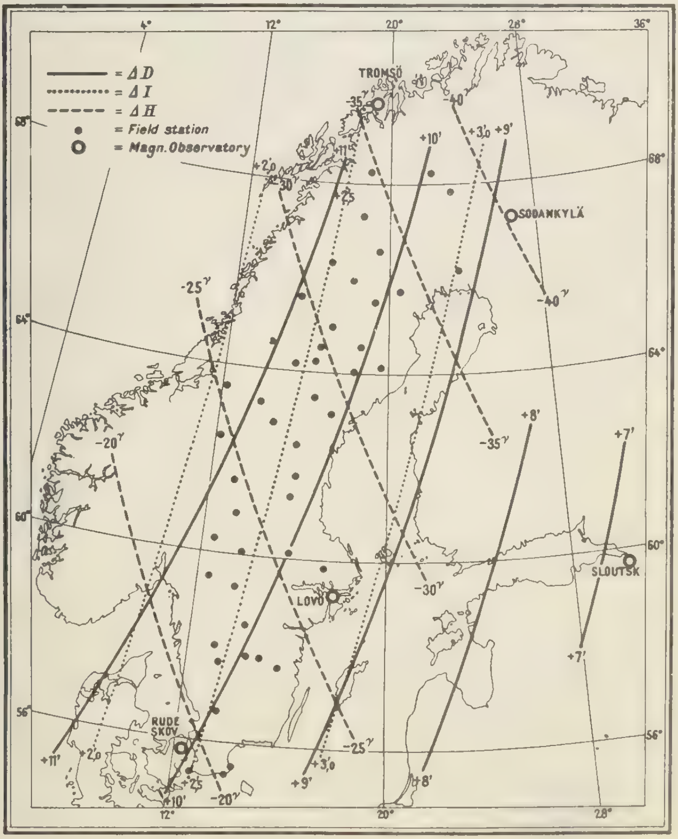

FIG. 1—PROVISIONAL ISOPORS IN SWEDEN DURING THE PERIOD 1929-36

The observations from 1936 have not yet been reduced to the middle of year, but they are preliminarily corrected for diurnal variation. At all stations in the southern parts of the surveyed area, each element was determined four times, and in the northern parts six times. Because of the relatively great number of observations at each station, the provisional means might be sufficient for estimating the average secular change and its local variations during the interval 1929-36.

An attempt to draw "true" isopors (lines of equal secular change) proved this to be inconvenient. I therefore preferred to compute very smoothed isopors of D, I, and H, expressed as functions of the geographical coordinates ϕ and λ. The local peculiarities will then appear as departures from the computed values.

The coefficients could be computed easily by the method of least squares, but as this demands that the deviations follow the law of accidental errors, a graphical method of smoothing the isopors seemed preferable. The simple method thereby used is suggested by that of W. Van Bemmelen[2] but is somewhat modified.

The following results were obtained:

$$\triangle D = +10'.23 + 0'.16\ (\triangle\phi) - 0'.22\ (\triangle\lambda)$$
$$\triangle I = +\ 2'.60 - 0'.04\ (\triangle\phi) + 0'.10\ (\triangle\lambda) - 0'.003\ (\triangle\lambda)^2$$
$$\triangle H = -37^{\gamma}.3\ - 0^{\gamma}.80\ (\triangle\phi) - 0^{\gamma}.82\ (\triangle\lambda)$$

$\triangle\phi$ and $\triangle\lambda$ are the differences, counted in degrees, between the geographical positions of the stations and the central point; $\triangle\phi = \phi - 62°$ north and $\triangle\lambda = \lambda - 16°$ east.

The mean errors of a single determination, expressed as $\pm\sqrt{\Sigma\triangle^2/(n-1)}$ are: $\triangle D$, $\pm 0'.37$; $\triangle I$, $\pm 0'.17$; $\triangle H$, $\pm 2.3\gamma$.

It is evident that the values obtained are not valid beyond a limited area. If extended to the nearest magnetic observatories the provisional computed constants are given in Table 1. The "observed" values are

TABLE 1

Observatory	$\triangle D$		$\triangle I$		$\triangle H$	
	Obs.	Comp.	Obs.	Comp.	Obs.	Comp.
	′	′	′	′	γ	γ
Tromsö	+10.7	+10.8	+2.5	+2.6	−32	−36
Sodankylä	+ 9.2	+ 8.8	+2.9	+3.1	−40	−40
Sloutzk	+ 6.6	+ 6.8	+3.2	+3.5	−36	−37
Lovö (Stockholm)	+ 9.5	+ 9.4	+2.8	+2.9	−30	−27
Rude Skov (Copenhagen)	+10.4	+10.0	+2.2	+2.4	−20	−20

obtained by extrapolation and are only approximate.

When the resurvey is completed and the observations are properly reduced to a common epoch, the isopors will be computed anew. Already the preliminary values obtained suggest the existence of regions with anomalous departures from the "normal" secular change.

[2]Magnetic survey of the Dutch East-Indies, 1903-1907, Batavia, Obsns. Mag. Met., **30**, 1907, Appendix 1 (1909).

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THE ELECTRICAL CHARACTERIZATION OF DAYS—THE PRACTICE OF THE BRITISH METEOROLOGICAL OFFICE

By F. J. W. Whipple

The subject of the electrical characterization of days was on the agenda of the Lisbon meeting of the International Association for Terrestrial Magnetism and Electricity in 1933. Two papers, one by O. H. Gish and the other by O. W. Torreson, were communicated and a Committee was formed to deal with the subject. In his paper Gish remarks (p. 225 of the Comptes Rendus) that the long experience in the use of these character-numbers at the observatories of the British Meteorological Office would enhance the interest in a statement from that office regarding the full purpose and the merits of the scheme. The following note has been prepared in response to this suggestion.

The "electric character of the day" appears to have been invented when the Geophysical Journal of the Meteorological Office was first published in 1911. In each monthly number of that Journal a table was provided for data connected with Atmospheric Electricty and Terrestrial Magnetism as observed at Kew Observatory and a similar table for observations at Eskdalemuir Observatory. The familiar "magnetic character" was naturally given for each day and it may be surmised that Dr. W. N. Shaw (now Sir Napier Shaw) the Director of the Meteorological Office thought that it would be appropriate to include an entry, "electric character of day." It may also be surmised that the specification of the classification 0, 1, 2 in terms of the duration of negative potential-gradient was due to Dr. Chree, Superintendent of Kew Observatory, that Dr. G. W. Walker, the Superintendent of Eskdalemuir Observatory, proposed a classification in terms of the range of disturbance and that the two systems were combined in the more elaborate classification adopted for the records of the latter observatory.

The classifications are explained in the Preface to the Geophysical Journal, 1911 as follows:

"The electric character of the day is indicated both for Kew and for Eskdalemuir by the figures 0, 1, or 2, according to the character of the trace of the electrograph as regards negative electric potential; thus 0 means no negative potential, 1 means one or more excursions of limited duration to the negative side of the scale, 2 means negative potential extending in the aggregate over a number of hours.

"For Eskdalemuir an estimate is also given of the character of the days as regards the range of potential irrespective of sign within the hourly periods for which an estimate of the mean potential has to be made in the process of tabulation. This characterization of the day is indicated by the letters *a*, *b*, *c*, according to the range of oscillation within the hour, using a range of about 1000 volts (per meter) as a criterion: *a* means that for no hour of the day was there a range of 1000 volts, *b* means that that range of oscillation was reached in one hour at least but in fewer than six hours, and *c* means that the critical range was reached in six hours or more.

"These specifications must not be understood to be rigid criteria. More definite specifications can be given after longer experience."

The definition of the numerical characters was made more precise as from the beginning of 1914 and now runs "Of the character figures, 0 denotes the absence of negative potential, 1 implies the existence of negative potential at one or more times during the day but with a total duration of less than three hours, while 2 implies the existence of negative potential with a total duration of three hours or more."

The significance of the character-letters *a*, *b*, *c*, has not been changed[1].

The complete Eskdalemuir code is also in use at Lerwick Observatory.

Since 1928, in accordance with a resolution of the International Union of Geodesy and Geophysics (Section for Terrestrial Magnetism and Electricity, Prague Meeting 1927), the daily duration of negative potential-gradient has been published in the Observatories' Yearbook for each of the three observatories. The practice of publishing the character-figures which indicate the days on which the duration of negative potential-gradient is greater or less than three hours has however been continued.

Kew Observatory: The character-figures 0, 1, and 2—The character-figures have not been utilized hitherto in any discussion of the records at Kew Observatory. At this Observatory the monthly calculation of the diurnal variation of potential-gradient is based on the records for ten quiet days. Normally these are ten days with character 0; "other objects aimed at in the selection of the days are freedom from large irregular movements and the avoidance as far as possible of large non-cyclic change. It is sometimes necessary to complete the number of ten quiet days in a month by including a 24-hour period which did not commence at midnight."

The most direct use we can make of the character-figures is to count them up. The frequencies of the different figures in recent years are set out in Table 1 and for comparison the frequencies of rainfall within given limits are added.

On the average there are 184 days in the year with character 0, that is, with no negative potential-gradient, and 42 days with character 2, that is, with negative potential-gradient lasting in the aggregate for more than three hours.

According to general experience it is to be expected that days of character 0 will be the days of no precipitation and days of character 2 will be the days with considerable precipitation. Table 1 shows that on the average the days with not more than 0.1 mm of rain are more numerous than the days with electric character 0. This indicates that days with practically no rain but with spells of negative potential-gradient are more common than days with appreciable rain but no negative potential-gradient.

The data for the year 1931 were analyzed to obtain a more definite view of the distribution of the character-figures between days with more or less rainfall. The results are set out in Table 2. In 1931 there were 22 days with character 0 but appreciable rain, but there were no less than 39 days on which precipitation less than 0.2 mm was associated with

[1]As long as tabulations were for the hours $23^h 30^m$ to $0^h 30^m$, $0^h 30^m$ to $1^h 30^m$, etc., the day for the purpose of the *a*, *b*, *c* classification contained 25 hours; from 1932 the tabulations have been for the hours 0 to 1, 1 to 2, etc., and this anomaly has disappeared.

TABLE 1—*Distribution of days with given electric character-figures and of days with rainfall between specified limits at Kew Observatory, 1914-35*

Character	Duration of neg. P.-G. in hours	Year											Mean
		1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	
0	0	183	187	165	185	187	189	196	237	180	180	175	
1	0.1 to 2.9	112	118	152	157	153	137	143	114	151	152	153	
2	3 or more	70	60	49	23	25	39	27	14	34	33	38	
		1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	
0	0	183	180	180	176	211	176	198	195	187	154	141	184
1	0.1 to 2.9	135	137	130	150	119	140	126	132	140	148	161	139
2	3 or more	47	48	55	40	35	49	41	39	38	63	63	42
Rainfall in mm		1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	
0 or 0.1		198	207	184	191	186	204	205	259	202	197	189	
0.2 to 1.0		55	53	56	67	69	62	54	43	49	47	50	
1.1 to 5.0		71	46	69	65	67	49	72	45	76	80	74	
More than 5.0		41	59	57	42	43	50	35	18	38	41	53	
		1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	
0 or 0.1		201	203	202	191	234	199	215	213	238	216	197	206
0.2 to 1.0		47	52	43	54	40	44	42	47	31	52	54	51
1.1 to 5.0		79	67	62	76	55	79	71	77	66	71	72	68
More than 5.0		38	43	58	45	36	43	37	29	30	26	42	41

character 1 or 2. However on ten of the 39 days there was 0.1 mm of precipitation and no doubt on many more there was rain too slight for measurement in the rain-gage.

There were five days in the year with more than a millimeter of rain but with no negative gradient, a notable example occurring on September 23 when there were numerous showers, yielding in the aggregate 2.9 mm of rain, but the gradient was positive and fairly high all day. On the other hand there was one day on which negative gradient persisted for more than three hours though there was not as much as 0.1 mm of rain. On this occasion (July 16, 1931) there was actually very slight rain. One instance has been discovered however (April 29, 1922) of a thunderstorm in the neighborhood producing very large gradients of varying sign for more than one hour and then continuously negative gradient for more than two hours without any rain falling at the Onservatory.

A curious feature of Table 1 is the notable increase at Kew in the last three years in the difference between the number of days with character 0 and the number of days with negligible rainfall. This is due to the frequent occurrence in these years of negative gradient in fine weather. This phenomenon occurs at night with northeast wind and must be quite local as it was not recorded by an electrograph installed at South Kensington, 12 km away. The phenomenon has not been explained.

It is perhaps a disadvantage of the method of allocating characters that no distinction is made between the days when negative gradient is associated with rain and the days when some other cause is operating.

A sub-classification would have to take account of the occasions on which negative gradient appears to be associated for part of a day with one cause and for part with another.

TABLE 2—*Distribution of days according to amount of precipitation and electric character (duration of negative gradient) at Kew Observatory, 1931*

Character	Precipitation in millimeters					Total
	0	0.1	0.2 to 1	1.1 to 5	>5	
0	165	11	17	5	0	198
1	28	10	23	52	13	126
2	1	0	2	14	24	41
	194	21	42	71	37	365
	215					

Eskdalemuir and Lerwick: The 0, 1, and 2 classification—For the comparison of conditions at Eskdalemuir and Lerwick with those at Kew the primary classification according to the duration of negative potential-gradient may be used.

Table 3 is comparable with Table 1. It will be seen that the days with no appreciable rainfall are much less common at the Scottish stations and, in accordance with expectation, days of electrical character 0 (that is, days with no negative potential-gradient) are also less frequent.

The preponderance at Lerwick of days with character 1 (negative potential-gradient lasting less than three hours) is very marked and is clearly associated with the large number of days with moderate rainfall.

TABLE 3—*Distribution of days with given electric character-figures and of days with rainfall between specified limits at Eskdalemuir and Lerwick Observatories, 1928-34*

Observatory	Character	Duration neg. P.-G. in hours	Year							Mean
			1928	1929	1930	1931	1932	1933	1934	
Eskdalemuir.....	0	0	90	141	111	117	120	149	109	120
	1	0.1 to 2.9	135	133	153	159	137	140	153	145
	2	3 or more	123	91	101	89	109	76	103	100
Lerwick.........	0	0	110	104	91	97	90	126	99	103
	1	0.1 to 2.9	174	186	213	206	217	184	202	198
	2	3 or more	78	72	58	62	59	55	64	64
	Rainfall in mm		1928	1929	1930	1931	1932	1933	1934	Mean
Eskdalemuir.....	0 or 0.1		128	158	133	124	149	170	127	141
	0.2 to 1.0		41	45	45	57	49	53	53	49
	1.1 to 5.0		69	66	85	89	70	76	84	77
	More than 5.0		128	96	102	95	98	66	101	98
Lerwick.........	0 or 0.1		117	113	108	118	109	123	95	112
	0.2 to 1.0		61	76	70	77	77	88	74	75
	1.1 to 5.0		110	108	120	113	119	97	120	112
	More than 5.0		78	68	67	57	61	57	76	66

The double classification adopted at Eskdalemuir and Lerwick—It will be remembered that, whereas the numbers 0, 1, 2 are allotted according to the duration of negative gradient, the letters *a*, *b*, *c* are allotted according to the number of hours with a wide range of potential gradient.

For comparison the entries in the years 1929-31 have been counted. These are expressed as percentages in Table 4. Data for Kew have been brought into Table 4 though only the single classification is adopted there. A special tabulation has been made for the three years in question.

TABLE 4—*Percentage distribution of days according to electric character, 1929-31*

Hours with range exceeding 1000 v/m	Classification	Observatory											
		Kew				Eskdalemuir				Lerwick			
		Negative gradient				Negative gradient				Negative gradient			
		None	>3hr	>3hr	Sum	None	>3hr	>3hr	Sum	None	>3hr	>3hr	Sum
		Character				Character				Character			
		0	1	2		0	1	2		0	1	2	
None	*a*	53	17	1	71	33	17	1	51	26	20	2	48
1 to 5	*b*	0.2	17	7	24	0.5	21	11	33	0.6	28	10	39
6 to 25	*c*	0	1	4	5	0	2	14	16	0	7	6	13
Sum	.	53	35	12	.	34	40	26	....	27	55	18	.

"0-days," that is, days with no negative gradient, were in the years of the tabulation twice as frequent at Kew as at Lerwick. "2-days," that is, days with more than three hours of negative gradient, were twice as frequent at Eskdalemuir as at Kew.

It will be seen that the designation 0*b* is infrequent and 0*c* never occurs. In other words it is but rarely that a range of 1000 v/m in an hour occurs without any negative gradient. Before Table 4 was made it was anticipated that at Kew, where large gradients accompany fog, there would probably be a fair number of 0*b*-days but actually on a foggy day the high gradient develops gradually without the occurrence of a large range in any particular hour.

Table 4 indicates that 1*b* and 1*c* are together a little more common than 1*a*. This means that on a day with negative gradient lasting less than three hours it is more likely than not that there will be some hours with a large range of gradient.

Finally 2*b* and 2*c* are equally common, that is, in a day with a total duration of negative gradient of three hours or more it is quite uncertain whether there will be six individual hours with a range of 1000 volts per meter.

Character and diurnal variation of potential gradient—In the Observatories' Year Book (as in its predecessor Part IV of the British Meteorological and Magnetic Year Book) there are two diurnal-variation tables for potential-gradient at Eskdalemuir. The first table is devoted to 0*a*-days, that is, days in which there was no negative potential-gradient and no hour with a range exceeding 1000 v/m. As we have seen already few days are excluded by the latter condition. The selected days are comparable with the "quiet days" selected at Kew Observatory.

The second diurnal-variation table is devoted to 1*a*- and 2*a*-days, that is, days on which negative potential-gradient occurs but in which there is no hour with a range exceeding 1000 v/m.

For Eskdalemuir mean values for the period 1913 to 1923 are represented in Figure 1, which is based on a table prepared by H. W. L. Ab-

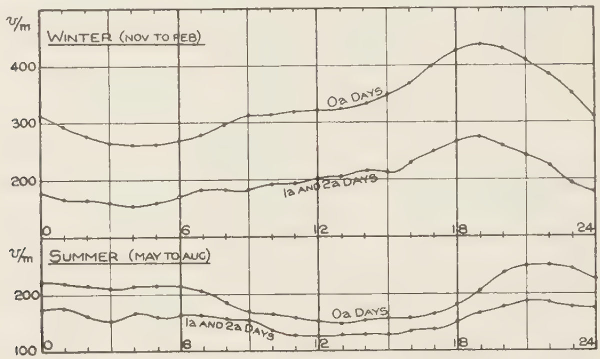

FIG 1—ESKDALEMUIR, 1913-1923 DIURNAL VARIATION OF POTENTIAL GRADIENT ON 0a-DAYS AND ON OTHER 'a'-DAYS, WINTER AND SUMMER; NON-CYCLIC CHANGE ELIMINATED

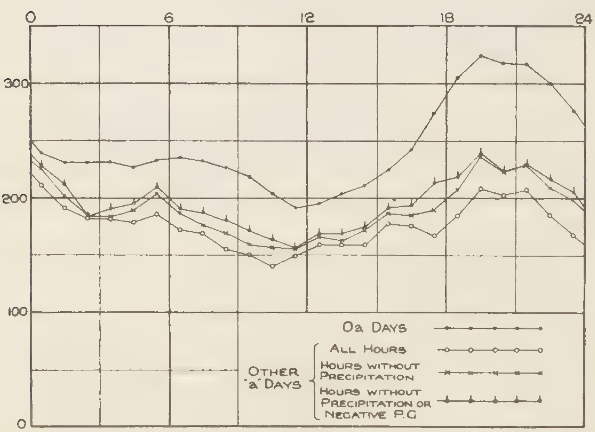

FIG 2—ESKDALEMUIR, 1933 DIURNAL VARIATION OF POTENTIAL GRADIENT ON 0a-DAYS AND OTHER 'a'-DAYS; EFFECTS OF PRECIPITATION, ETC.

salom. It will be seen that the average potential-gradient on the 1*a*- and 2*a*-days is less than the average gradient on the 0*a*-days. This is true for all hours and for all seasons; the contrast is least in summer and in the middle of the day. The lower averages are no doubt due, to a certain

extent, to the fact that the occurrence of negative potential-gradient for part of an hour must tend to reduce the average gradient for that hour, a mere matter of arithmetic. It is not obvious however whether this is the whole story. Is the gradient likely to be high or low on those hours of a day of character 1 or 2 in which there is no precipitation? To obtain an answer to this question the Eskdalemuir tabulations for the year 1933 were utilised, the entries for hours in which precipitation had occurred being eliminated and then the entries for other hours in which there had been some negative gradient.

The results are exhibited in the graphs of Figure 2. These show that the low average gradient on a 1*a*- or 2*a*-day is a characteristic of the electric conditions throughout the day. It is likely that the days in question are days when the air has high conductivity but this requires experimental verification.

Having learned that the gradient is low on a 1*a*- or 2*a*-day we enquire whether the gradient will tend to be low or high on *b*- and *c*-days. Complete hourly values of potential gradient for *b*- and *c*-days are not tabulated at Eskdalemuir and Lerwick but the hourly values at 3, 9, 15, and 21 are available for those stations in the Observatories' Year Book. I have extracted data for Eskdalemuir for 1932 and 1933. No data were utilised for hours in which precipitation had occurred or for which the mean gradient was negative. The numbers of readings satisfying the criteria and used in finding the mean values are given in Table 5 which shows for instance that there were 135 *b*- or *c*-days in the twelve summer

TABLE 5—*Potential-gradient at fixed hours on days with different characters at Eskdalemuir, 1932 and 1933, hours with precipitation or negative potential-gradient being ignored*

Half-year	Classification	Days used	No. of hours used				Mean potential-gradient			
			2–3	8–9	14–15	20–21	2–3	8–9	14–15	20–21
Winter	0*a*	129	108	124	119	118	274	259	250	389
	1*a*+2*a*	50	42	39	39	38	168	182	229	291
	b+ *c*	186	90	107	101	113	190	208	209	302
Summer	0*a*	140	131	130	132	129	195	171	150	252
	1*a*+2*a*	91	77	76	66	69	169	149	133	191
	b+ *c*	135	87	66	72	81	179	173	142	195

months of the two years and further that 66 of these days yielded good readings for the hour 8 to 9. The corresponding mean value of potential-gradient was 173 v/m. The figures show that the fluctuations of potential-gradient in the course of the day are of similar type on *b*- and *c*-days and on 1*a*- and 2*a*-days. Further it is only in winter that there is an outstanding difference between these and the 0*a*-days. It is well known that when the violent fluctuations of potential-gradient which accompany heavy rain have passed away potential-gradient returns to about the normal fine-weather value. The analysis shows that the agreement is close. In fact the potential-gradient in the fine part of a very wet day is about the same as that in the fine part of a day with a little rain and a little less than that prevailing in the course of a day which is fine throughout.

This examination of the data from Eskdalemuir shows that it may be profitable to study not only the diurnal variation of potential-gradient on days on which the gradient is continuously positive but also the diurnal variation on other days. I am not satisfied however that it is worth while to introduce the *a*, *b*, *c* notation for this purpose.

For comparing the climate of one place with that of another the classification of the days according to the occurrence of negative gradient may be regarded as primary. It is already recommended that the duration of negative gradient shall be estimated day by day. To adopt the Meteorological Office classification is merely to distinguish between the days on which the duration is zero, less than three hours, and at least three hours. The extension to other parts of the world of statistics such as those given for Kew, Eskdalemuir, and Lerwick in Tables 1 and 3 above would be of considerable interest and it may be hoped that the simple scheme will be generally adopted.

My thanks are due to Dr. A. H. R. Goldie for letting me have the data incorporated in Figures 1 and 2 and to Mr. E. Boxall for much assistance in the preparation of Tables.

Kew Observatory,
March 2, 1937

INTENSITY-MEASUREMENTS OF THE COSMIC RADIATION IN CAPETOWN DURING 1933, 1934, AND 1935

By B. F. J. Schonland, B. Delatizky, and J. Gaskell

Abstract—This paper presents an analysis of the results of three years' photographic registration of the ionizing power, briefly called the intensity, of the cosmic radiation in Capetown, South Africa. The measurements, which were made at hourly intervals, have been undertaken as part of an international scheme under the general direction of Dr. E. Steinke of the University of Königsberg. The instrument used is one of a number of identical construction and mode of operation made under Dr. Steinke's supervision. The data obtained from this and the other stations of the group are to be collated and compared in a forthcoming publication. They have already been utilized in a joint report upon the intensity of the radiation at the time of the appearance of Nova Herculis[1].

No long-continued observations of this nature have yet been made in the Southern Hemisphere and as the Capetown station is the only one of the group situated below the Equator its results are of special interest.

1—*Site and equipment*

The station is situated in latitude 33° 57′ south and longitude 18° 28′ east; its geomagnetic latitude is 32° south. For the first nine months of operation, from February to October 1933, the instruments were installed in an upper room in the Physics Department of the University, 103.0 meters above sea-level (Site 1). The roof of this room was of tile, thickness 3.6 grams per square centimeter, and the walls were of brick, thickness 80 grams per square centimeter. The rays were first interrupted by walls at a zenith-angle of 45°.

In mid-November 1933 the station was moved to a hut a short distance away and 122.0 meters above sea-level where it has remained (Site 2). The roof of this hut is of thatch, thickness 3.4 grams per square centimeter, and the walls of compressed cane-board (celotex) of total thickness 0.4 grams per square centimeter. These walls are made of two sheets of board, separated by air-pockets in the frame between them, so as to minimize changes of temperature inside the hut. Rays first encounter the walls at a zenith-angle of 40°.

The slopes of Table Mountain, extending from the northwest to the southwest of the site, offer the only external obstruction to the path of the rays. Over a range in azimuth of 30° they limit reception to zenith-angles between 0° and 75° and for a further 30° in azimuth, to zenith-angles between 0° and 80°. The total resultant screening-effect is estimated from a table due to Compton to be 0.3 per cent[2].

The Steinke apparatus used for the measurements has been described elsewhere[3]. In principle it consists of a steel ionization-chamber of thickness three mm and volume 22.6 liters filled with CO_2 at a pressure of 10.09 kg/cm^2 at 0° C and enclosed in a 10-cm lead shield. No measurable leakage of gas has occurred during three years of operation. The walls of this chamber are maintained at a constant difference of potential with respect to the Earth of 170 volts, supplied by a battery of standard

[1]E. Steinke *et al.*, Zs. Tech. Physik, **16**, 397-400 (1935).

[2]A. H. Compton, Phys. Rev., **43**, 392, Table 2, (1933).

[3]A. Corlin, Ann. Obs., Lund, No. 4 (1934).

cadmium cells. The charge acquired by the central collecting-electrode is compensated by an induced charge from a condenser (capacity 15.175 cm as determined by Dr. E. Steinke before despatch) which is automatically increased by a potential-divider in regular steps each half-minute. This was driven by a clock whose rate was determined as often as was necessary and later by a synchronous motor running on the supply mains. The departure from final compensation at the end of a run of 57 minutes is determined by taking a photographic record of the position of the needle of a Lindemann electrometer at the beginning and end of the run. A third record of the "earthed" position of the needle prevents possible kicks, produced on freeing the system from earth, from falsifying the readings. The total compensating charge applied during the run is measured in terms of the current flowing through the potential-divider. The factor by which this current in microamperes has to be multiplied to obtain the ionizing power of the rays in standard J units (ions per cc per sec in normal air; one mJ is 1/1000 of this unit) is 1.753 as determined by Dr. E. Steinke before despatch.

The cylindrical ionization-chamber was set with its axis along the magnetic meridian and surrounded with a lead shield 10 cm thick. The instrument was operated under these conditions (*Vollpanzer*, referred to as *VP*) from the twentieth day of each month to the tenth day of the following month. From the tenth to the twentieth of each month the top of the lead shield was removed to allow softer radiation to enter the chamber (*Halbpanzer*, referred to as *HP*). In this case the cylinder was open to the radiation in the meridional plane from 0° to approximately 61° and in the east-west plane from 0° to 45°.

The instrument is supplied with an ammeter on which the compensating current is read, but this was replaced by a Tinsley potentiometer and a standard resistance, capable of reading the current to a few parts in 10,000. The observational accuracy of the instrument, including the reduction of the photographic registrations, was at all times at least one part in 2000.

Every hourly observation was reduced to the value it would have had under a standard external pressure of one atmosphere, using the methods of reduction described in a later section. The readings of pressure were obtained from a recording barograph checked frequently against a standard barometer.

2—*Temperature-variations and inner temperature-coefficient*

During the period reported upon in this paper it was not found possible to install automatic control of the temperature of the apparatus. Any large variation of temperature with time of year was prevented by running an electric heater during the colder weather, and the hut was designed to reduce the diurnal fluctuation in temperature as much as possible. The mean annual temperature of the instrument was 20°.6 C, the temperature for spring, summer, autumn, and winter differing from this mean by −0°.5, +1°.8, 0°.0, and −1°.1 C, respectively.

The amplitude of the diurnal fluctuation of temperature in the hut for the same four seasons was ±1°.5, ±2°.3, ±2°.0, and ±1° 5 C as determined by a continuously recording thermograph. No difference in the temperature inside and outside the lead shield was found and there

appeared to be no appreciable lag in the temperature of the instrument behind that of the air in the hut—tests with two thermographs indicated a lag of less than 30 minutes.

The temperature-coefficient of the instrument has been directly determined by a series of observations in the course of which the temperature of the hut—kept constant to within 0°.5 C by a thermostatic device—has alternated in successive weeks between 27° C and 19° C. The values thus found for the "inner" temperature-coefficient lie between +0.10 per cent and +0.14 per cent per degree C. A similar figure has been given by Steinmaurer[4], who found a coefficient of +0.2 per cent per degree C, about half of which was due to the ammeter control-spring. In our case, as noted above, this ammeter was not used.

3—*The barometer-effect*

The chief difficulty attending the measurement of the intensity of the cosmic radiation over long periods arises from variations in the absorption, scattering, and degradation of energy, processes in the atmosphere above the station. Reduction to standard atmospheric conditions is therefore essential if observations which have been made at different times are to be compared. This is generally done by determining the mean rate of change of intensity with atmospheric pressure over a long period, determining the coefficient of the barometer-effect β, and then reducing each observation to a standard pressure. Since a reduction of this kind ignores the fact that the radiation is not incident in the vertical direction, as well as the possible effects of atmospheric stratification, it is of importance to determine to what extent such reduced observations are strictly comparable.

The stations of the Steinke group proceed by finding separate values of β for each separate period of ten days' observation. These 240 hours' observations are used to find the correlation-coefficient, r, and the slope of the first regression-line, β, defined by the relation[5]

$$I - I' = (\sigma_2/\sigma_1)\ (B - B') = \beta\ (B - B')$$

where I' and B' are the mean values of the intensity and of the barometric pressure during the period, I and B are the values for any particular observation. The coefficient β is found to be negative in sign.

The values of β expressed in *mJ/mm* of mercury are shown in Table 1 for *VP*, and in Table 2 for *IIP*. The value of the correlation-coefficient r found for each period is shown by the symbol attached to it. For the 88 ten-day periods included in Tables 1 and 2, the correlation-coefficient exceeded 0.95 thirteen times, 0.90 twenty-eight times, and 0.85 sixty-three times.

Whether these high correlation-factors are sufficient to justify the somewhat varied values of the barometer-coefficient shown in Tables 1 and 2 appears to us still somewhat uncertain. The values of β vary considerably amongst themselves and the variations are just outside the probable limits of error in the most extreme cases. For example the periods centered on January 25, 1936, and October 25, 1935, each have correlation-factors of 0.95 ± 0.02 and give values of -2.66 ± 0.37 and

[4]Beitr. Geophysik, **45**, 148-183 (1935)

[5]V. F. Hess, Wien. SitzBer. Ak. Wiss., IIa, **144**, 53-64 (1935).

-3.48 ± 0.49 for β, respectively. Gaps in Tables 1 and 2 marked with asterisks indicate that the actual observations were too few to give satisfactory values for β. In such cases a mean value was employed in the reductions.

TABLE 1—*Coefficient of the barometer-effect, β, in mJ/mm of mercury for full shield (Vollpanzer)*

Season	Period centered on	Year				All years
		1933	1934	1935	1936	
Southern summer	December 25	....	3.16[a]	3.23[b]	2.46[c]	
	January 5	....	4.17[b]	....	2.80[c]	
	January 25	....	3.64[b]	....	2.66[a]	
	February 5	....	3.00[b]	....	....	
	February 24	....	3.18[c]	....	4.23[a]	
	March 5	(1.78)	2.95[d]	4.96[b]	....	
	Means	....	3.35	4.09	3.04	3.49
Southern autumn	March 25	3.63[b]	*	(2.52)		
	April 5	*	2.39[c]	5.49[b]		
	April 25	3.65[b]	....	3.72[b]		
	May 5	4.10[b]	3.27[b]	3.10[c]		
	May 25	2.80[b]	3.36[b]	4.30[b]		
	June 5	3.67[b]	3.51[b]	*		
	Means	3.57	3.13	3.71		3.47
Southern winter	June 25	5.50[c]	3.91[b]	4.05[b]		
	July 5	3.56[b]	3.39[a]	3.04[c]		
	July 25	3.52[b]	3.91[b]	3.68[b]		
	August 5	2.37[b]	2.76[b]	4.09[b]		
	August 25	3.02[b]	3.27[b]	3.11[c]		
	September 5	3.37[b]	....	3.83[b]		
	Means	3.56	3.45	3.66		3.56
Southern spring	September 25	3.28[b]	*	3.34[a]		
	October 5	3.35[b]	*	2.77[c]		
	October 25	4.15[b]	3.18[c]	3.48[a]		
	November 5	4.49[b]	3.01[b]	2.89[c]		
	November 25	4.00[b]	4.65[c]	3.60[b]		
	December 5	4.51[b]	*	3.35[b]		
	December 15	3.23[b]	....	....		
	Means	3.86	3.61	3.24		3.57
	Annual means	3.66	3.36	3.67		3.52

[a] $r>0.95$. [b] $r>0.85$. [c] $r>0.65$. [d] $r>0.55$.

*Observations not sufficiently numerous.

Tables 1 and 2 show the mean annual values of β to have been -3.66, -3.36, and -3.67 *mJ/mm* for *VP* and -7.41, -8.39, and -8.57 *mJ/mm* for *HP*. The smaller value for the 1933 *HP*-observations is no doubt due to the slight hardening of the radiation in passing through the walls of Site 1. No significant change with season is apparent.

For the whole three-year period the barometer-coefficients are -3.52 *mJ/mm* under *VP* and -8.1 *mJ/mm* with *HP*. When the former is ex-

TABLE 2—*Coefficient of barometer-effect, β, in mJ/mm of mercury for top shield off (Halbpanzer)*

Season	Period centered on	Year			All years
		1933	1934	1935	
Southern summer	December 15	....	10.5^b	9.00^a	
	January 15	....	9.7^b		
	February 15	....	11.4^b		
	Means	....	10.6	...	(10.2)
Southern autumn	March 15				
	April 15	12.3^c	11.0^c	$(5.0)^d$	
	May 15	4.1^d	7.7^c	12.8^b	
	Means	8.2	9.4	8.9	8.83
Southern winter	June 15	7.0^b	8.2^c	10.9^c	
	July 15	7.2^a	6.0^c	7.5^a	
	August 15	6.1^c	7.1^b	6.2^b	
	Means	6.8	7.1	8.2	7.70
Southern spring	September 15	5.9^b	6.7^b	11.1^a	
	October 15	6.3^b	6.9^b	7.4^a	
	November 15	10.4^b	7.1^c	7.2^a	
	Means	7.5	6.9	8.6	7.70
	Annual means	7.41	8.39	8.57	8.12

$^a r>0.95$. $^b r>0.85$. $^c r>0.65$. $^d r>0.55$.

pressed as a percentage-change in the total intensity of the cosmic radiation itself, with local and other effects subtracted (see section 4) it becomes −0.216 per cent per mm. A value of 0.18 per cent per mm has been found by Messerschmidt[6] in Halle with a different instrument under the same thickness 10 cm of lead while Steinke in Königsberg has reported 0.20 per cent per mm under 12 cm of lead. These are the only sea-level results of comparable accuracy which we have been able to find. They indicate that the radiation in Capetown is softer than would have been expected from the geomagnetic latitude.

For the mass absorption-coefficient inside 10 cm of lead the formula of Kolhörster and Tuwim, which takes into account hemispherical incidence of the radiation on the outer atmosphere, yields 0.0011 per gram per square centimeter of H_2O.[7]

When the mean daily intensity is plotted against the mean daily pressure the resulting curve over a period of several days frequently takes the form of a closed loop as shown in Figure 1, in which the continuous curve runs from August 1 to 7, 1934, and the dotted curve from August 7 to 10, 1934, and where the means are taken for sets of six hours of observations. In this case the loop is described in a clockwise direction, the intensity of the radiation being less during a falling than during a rising barometer-period. Each ten-day period of observation has been ex-

[6] W. Messerschmidt and W. Pforte, Zs. Physik, 73, 677-680 (1932).

[7] Ergebn. kosm. Physik, 1, 127-179 (1931).

amined for evidence of this "secondary" barometer-effect. It is found to have occurred to a marked extent in 38 cases—the majority of which, 29 cases, gave clockwise loops. No seasonal effect is evident in the distribution of either type of loop.

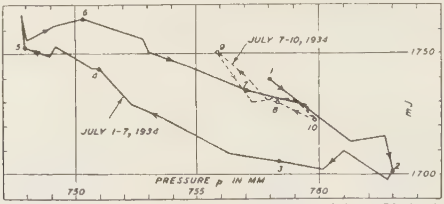

FIG. 1—VARIATION MEAN DAILY COSMIC-RADIATION INTENSITY WITH ATMOSPHERIC PRESSURE, CAPETOWN

4—*Absolute value of intensity in Capetown*

The mean value for the total intensity observed under full shield (*VP*) for the three years is 1.701 *J*. This represents the ionizing power of the cosmic radiation plus that of the walls of the vessel and that of the gamma radiation from the Earth. The effect of the emanations in the air has been shown by Messerschmidt[8] to be negligible in the case of an instrument completely screened by 10 cm of lead.

In order to find the effect of the cosmic radiation alone, we first subtract that due to the walls. This was estimated by Steinke before despatching the instrument to be 60 *mJ*, while that of a similar instrument tested by Corlin[9] in a deep tunnel was 30 *mJ*. A mean value of 45 *mJ* will be taken for the wall-effect.

The effect of the radiation from the Earth may be estimated from some results obtained in Capetown by S. M. Naude[10], who found it to be 120 *mJ* inside a shield equivalent to 7 cm of lead at a point close to the present station. Assuming an absorption-coefficient in lead of 0.50 cm^{-1} the Earth-radiation effect inside our shield should be 27 *mJ*.

Subtracting wall and local effects and increasing the result by 0.3 per cent to allow for the screening effect of the mountain (see section 1) we find for the absolute value of the intensity of the cosmic radiation in Capetown the value 1.634 *J*. This value is the ionizing power of the radiation inside 10 cm of lead at a height of 139 meters above sea-level and under a standard external pressure of 760 mm of mercury. [This calculation ignores the absorption in the roof of the hut, which is responsible for a reduction of about 7 *mJ*.] It has a probable error of one per cent arising from uncertainties in the subtraction terms. It is obtained at a mean external air-temperature of 16° C and temperature of instrument 20°.6 C.

5—*Magnetic-latitude effect*

Dr. Steinke very kindly tested the instrument in Königsberg before despatch and obtained 1.840 *J* for the total intensity there. Subtracting 45 *mJ* for the wall-effect and his own figure of 40 *mJ* for the local radiation-effect in Königsberg, the intensity at sea-level in Königsberg meas-

[8]Zs. Physik, 81, 99 (1933).

[9]Ann. Obs., Lund, No. 4, p. A44 (1934).

[10]A. H. Compton, Phys. Rev., 43, 387-403 (1933).

ured on the same instrument is 1.755 *J*. This difference between accurate measurements with the same instrument in Capetown and Königsberg is of interest in connection with the magnetic-latitude effect. Table 3 cites two other comparisons between intensities measured in similar latitudes.

TABLE 3

Observations between	Difference	Shield	Observers
Königsberg and Capetown	0 12 *J*	10 cm lead	Steinke-Schonland *et. al.*
Amsterdam and Capetown	0 10 *J*	8 cm iron[14]	Clay *et. al.*[11]
50° North and Capetown	0 14 *J*	7 cm lead[12]	Compton-Naude[10]

[11] J. Clay, P. van Alphen, and C. G. 't Hooft, Physica, 1, 829-838 (1934).

For the *HP*-observations, in which the top of the shield was removed, it is not practicable to estimate the absolute value of the intensity without more information as to the effect of the Earth- and air-radiations than we have at present.

We now proceed to discuss variations in the intensity of the radiation with time and season. Since the local and wall effects are small and very nearly constant for the case of the full screen (*VP*), no errors are likely to arise in the employment of the total instead of the absolute intensity in such comparisons. The local radiations may however be expected to play some part in the observed variations for the case of *HP* and thus the *HP*-observations are regarded as of secondary importance in this connection.

6—*Yearly variation in intensity—Annual means*

Annual mean values for the total intensity reduced to 76 cm external pressure are shown in Table 4. In the case of the *VP*-observations, readings are not available for January 1933 and February 1935, while *HP*-observations are lacking for January 1933 and the first three months of 1935. The *VP*-readings prior to November 1933 have been increased by 7 *mJ* to allow for the difference in altitude between Sites 1 and 2. No such correction can be made to the *HP*-values since the local radiations at the two sites are probably very different.

TABLE 4—*Annual mean intensities*

VP (Full shield)				*HP* (Top removed)		
Year	1933	1934	1935	Feb.-Oct. 1933	Nov. 1933-Dec. 1934	1935
Hours observed	4860	4992	4242	1224	2400	1680
Mean total intensity in *mJ*	1701	1702	1699	(3080)[a]	2396	2397

[a] Site 1; most of the excess in this case must arise from the brick walls of Site 1.

From the *VP*-observations we conclude that no alteration greater than one or two parts in 1000 occurred in the annual mean intensity of the radiation during this three-year period. This conclusion is supported by the constancy of the *HP*-values for 1934 and 1935. The mean sunspot-

numbers for the three years were 1.2, 0.6 and 1.0, the sunspot-activity passing through a minimum in 1933.

7—Seasonal variation of intensity—Monthly means

Monthly means of the total intensity reduced to standard external pressure are shown in Figure 2 for both *VP* and *HP* conditions. The *HP*-values obtained in Site 1 prior to November 1933 have been reduced by 685 *mJ* for comparison with the remainder, this figure being obtained from Table 4.

Both curves show a strongly marked seasonal variation with a maximum in the winter and a sharp minimum in the summer of the Southern Hemisphere[12]. A similar seasonal effect has been reported from the Northern Hemisphere[13]. The difference between winter and summer in our observations is about one per cent, taking means over three years. Steinmaurer from a single year's observations in Innsbruck finds two per cent for the same difference[4].

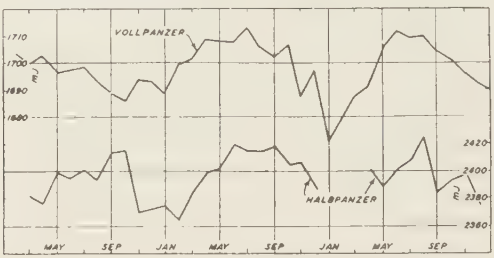

FIG. 2—MONTHLY MEANS, TOTAL COSMIC-RADIATION INTENSITY REDUCED TO STANDARD ATMOSPHERIC PRESSURE, CAPETOWN, 1933-1935

These observations have been examined to learn whether or not the seasonal fluctuation can be explained in terms of seasonal variation in the temperature of the outside air. The mean monthly *VP*-values of intensity when compared with the mean monthly air-temperatures at a meteorological station a few miles away give an outer temperature-coefficient of -0.12 per cent per degree C, which is not far from that directly determined by Steinmaurer[4] with a similar instrument (-0.09 to -0.11 per cent). This coefficient has been applied as a correcting factor to the mean monthly intensities in Table 5. It will be seen that the effect is to reduce the fluctuation in the original observations to half its previous value and to change the minimum from January to September. These results are shown graphically in Figure 3 where the thick-line curve re-

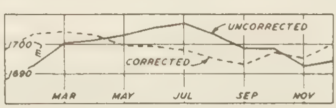

FIG. 3—MONTHLY MEANS COSMIC-RADIATION INTENSITY, CORRECTED AND UNCORRECTED FOR OUTSIDE TEMPERATURE, CAPETOWN, 1933-1935

[12]The value for January 1935 is not considered reliable.

[13]V. F. Hess, H. Th. Graziadei, and R. Steinmaurer, Wien, SitzBer. Ak. Wiss., *IIa*, 143, 313-338 (1934); see also footnotes 3 (p. *A*71) and 4.

fers to the uncorrected mean values for the three years and the dotted curve to the corrected values.

TABLE 5

Month	Means for years 1933, 1934, 1935		Cor-rection	Corrected intensity at 15°.7 C
	Temper-ature	Inten-sity		
	°C	mJ	mJ	mJ
January	19.8	1689*	+8.6	1698
February	20.4	1693	+9.9	1703
March	17.5	1700	+3.8	1704
April	16.8	1701	+2.3	1703
May	13.8	1703	−4.0	1699
June	12.8	1705	−6.1	1699
July	11.3	1707	−9.2	1698
August	12.0	1703	−7.8	1695
September	13.1	1698	−5.5	1693
October	15.1	1698	−1.3	1697
November	17.1	1692	+2.9	1695
December	18.6	1694	+6.1	1700

*Only one reliable month's observations.

Since it is unreasonable to suppose that the seasonal variation can be completely correlated with the local ground air-temperature—indeed the outer temperature-relation is obviously a crude approximation—

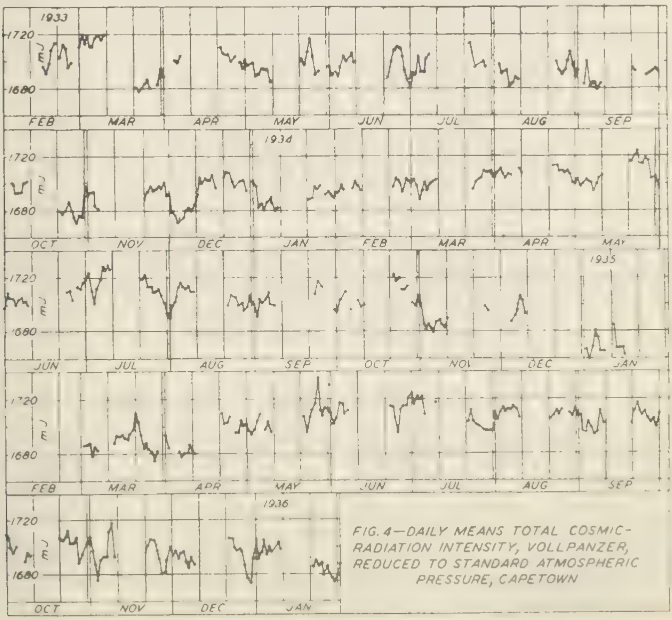

FIG. 4—DAILY MEANS TOTAL COSMIC-RADIATION INTENSITY, VOLLPANZER, REDUCED TO STANDARD ATMOSPHERIC PRESSURE, CAPETOWN

the degree of correction obtained in Table 5 suggests that seasonal variation in the general temperature and stratification of the atmosphere may well be solely responsible for the effects observed.

The *HP*-observations similarly treated yield a mean outer temperature-coefficient of -0.23 per cent per degree C but in this case the smoothing out of the seasonal variation is not very marked.

8—*Variations of the second kind—Daily means*

Daily mean values of the total intensity, reduced to standard pressure, are shown in Figures 4 and 5. In the case of days with satisfactory observations for less than 18 hours no mean was formed and for days with more than 18 but less than 24 hours the missing hours were replaced by the mean of the remainder. In Figure 4 vertical lines have been drawn on the 31st, 10th, 20th, and 30th of each month. In Figure 5 the observations begin on the 10th and end on the 20th of each month.

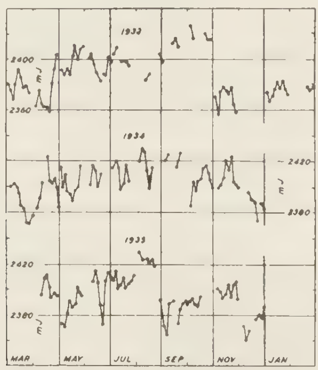

FIG. 5—DAILY MEANS FOR TENTHS TO TWENTIETHS OF EACH MONTH TOTAL COSMIC-RADIATION INTENSITY, HALBPANZER, REDUCED TO STANDARD ATMOSPHERIC PRESSURE, CAPETOWN

These figures show many examples of sudden fluctuations in intensity of from one to two per cent of the mean—the so-called variations of the second kind. In the majority of cases these are associated with rapid rise or fall of the barometer and with the occurrence of the secondary barometer-effect. Occasions when this relation was definite are indicated in Figures 4 and 5 by a wavy line.

9—*Variation with solar time—Hourly means*

In order to obtain values of the intensity from observations centered upon each hour instead of beginning at it, each individual hourly observation beginning at n^h has been meaned with its predecessor beginning at $(n-1)^h$ to obtain the intensity at n^h. Figures 6 and 7 show the manner in which this mean hourly intensity varies with local solar time. In both Figures the first curve is for the first nine months' period at Site 1, the second from November 1933 to December 1934 at Site 2, and the third from March 1935 to January 1936 at Site 2.

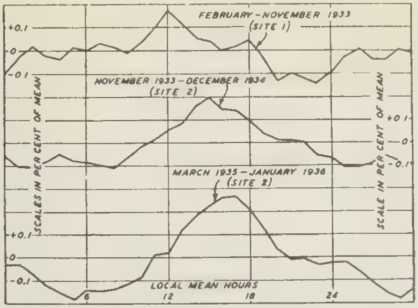

FIG. 6—DIURNAL VARIATION OF COSMIC-RADIATION INTENSITY, VOLLPANZER, CAPETOWN

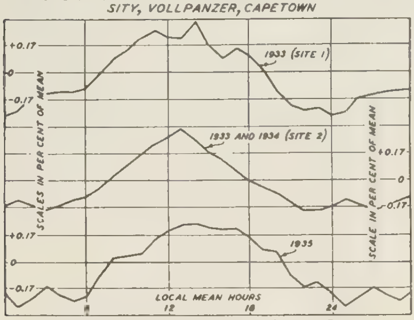

FIG. 7—DIURNAL VARIATION OF COSMIC-RADIATION INTENSITY, HALBPANZER, CAPETOWN

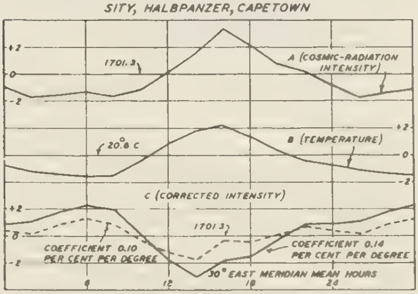

FIG. 8—CURVES SHOWING TEMPERATURE-EFFECTS ON COSMIC-RADIATION INTENSITY, CAPETOWN, 1934

All the curves show a sharp maximum in the afternoon. The time along the horizontal axis is Middle European Standard Time (MET) which is 14 minutes later than mean solar time in Capetown. The amplitude of the afternoon maximum reaches approximately 0.2 per cent of the mean intensity.

Before these curves can be accepted as giving a true variation of intensity with solar time, corrections must be applied for the effect of temperature on the observations. The first such correction arises from fluctuations of the temperature of the instrument, the nature of which has already been discussed in section 2. The inner temperature-coefficient

has been found to lie between $+0.10$ and $+0.14$ per cent per degree C. The result of applying this coefficient to the *VP*-observations of 1934 is shown in Figure 8 where the first curve, *A*, repeats the center curve of Figure 6, and the second, *B*, shows the mean temperature of the instrument at each hour of the day during that year. In this case the times along the horizontal axis are South African standard (30° east meridian) time, which is 3/4 hour ahead of mean solar time in Capetown. The two lower curves, *C*, show the effects of applying inner temperature-coefficients of $+0.14$ per cent per degree C (full line) and $+0.10$ per cent per degree C (dashed line), respectively. It will be seen that the afternoon maximum is now shifted to 6^h (5^hMET). A similar early morning maximum has been observed by Steinmaurer[4] with an identical instrument under controlled temperature-conditions at Innsbruck.

The second temperature-correction is that for the external air, discussed previously in section 7. We are not in a position to apply this correction to the present observations since no measurements of external temperature have been made at the site of the station and conditions are different at the nearest meteorological station. Since, however, the external temperature-coefficient (section 7) is approximately -0.12 per cent per degree C—opposite in sign to the internal temperature-coefficient—and since the daily fluctuation of external temperature is in approximately the same phase as that of the internal temperature, its effect must be to restore the curves to practically the same form as that shown in Figures 6 and 7 without any correction. The larger amplitude of the external temperature-variation—about twice that of the internal tem-

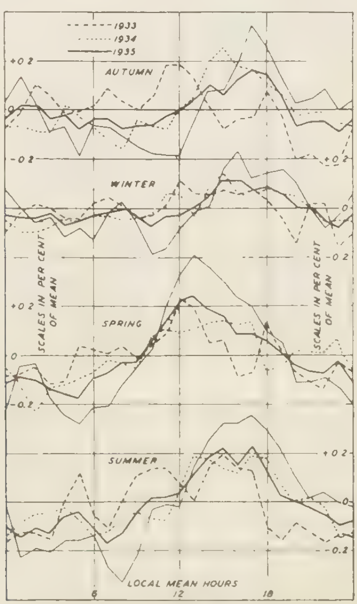

FIG. 9—SEASONAL DIURNAL VARIATION COSMIC-RADIATION INTENSITY, VOLLPANZER, CAPETOWN

perature-variation—should thus produce a final corrected variation with solar time showing an afternoon maximum about 14^h with an amplitude of some 0.3 per cent of the mean. This conclusion is similar to that reached by Hess [13, 14] and Steinmaurer[4] for the Northern Hemisphere.

Figures 9 and 10 show the observed variation of intensity with solar time at various seasons and for different years. It may be noted that in the case of the *VP*-observations the variation is smallest during the winter months when variations of temperature, inside as well as outside, are least.

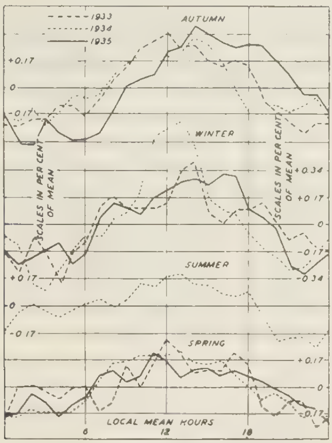

FIG. 10—SEASONAL DIURNAL VARIATION COSMIC-RADIATION INTENSITY, HALBPANZER, CAPETOWN

10—*Variation of intensity with sidereal time*

The curve shown in Figure 11 exhibits the variation in the total intensity with local sidereal time for the year beginning in February 1933, under *VP*-conditions. In preparing the data each observation has been allotted the correct sidereal time and then classed according to the sidereal hour or half-hour nearest to this time. The average of the root-mean-square deviations for each hour or half-hour (0.07 per cent) is indicated in the usual manner at the left of the curve. The curve so

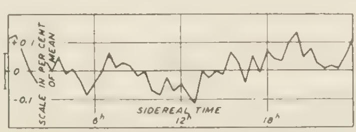

FIG. 11—SIDEREAL-TIME DIURNAL-VARIATION COSMIC-RADIATION INTENSITY, VOLLPANZER, CAPETOWN, FEBRUARY TO DECEMBER, 1933

obtained shows no sudden variation of consequence, such as might be due to a strong source of the rays in a particular direction, but does exhibit maxima at 20^h and 24^h and a good minimum at 12^h.

[14]V. Hess and H. Th. Graziadei, Terr. Mag., **41**, 9-14 (1936).

The labor involved in such a reduction (which was done for us by Dr. Steinke's bureau) is considerable and it was necessary to adopt a simpler method for the years 1934 and 1935. For these years the hourly observations over each period of ten days have been regarded as having been made at the sidereal times of similar observations on the central day of the period. This procedure gives rise to an average error of ten minutes in the sidereal time and a maximum error of 20 minutes for the extreme days at the beginning and end of each period. The curves obtained in this way for 1934 and 1935 are shown with that for 1933 at the top of Figure 12, hourly values being plotted.

In order to eliminate as far as possible the effects of solar-time variations and the inner and outer temperature-effects, it was necessary to arrange that each "year" contained a complete set of observations. Gaps in the observations for VP were filled by the substitutions shown in the following list.

Year	Missing	Replaced by
1933 (Feb. 1, 1933, to Jan. 31, 1934)	None	None
1934 (Feb. 1, 1934, to Jan. 31, 1935)	November 20-30	November 1-10, repeated
	December 20-31	January 1-10, 1935, repeated
1935 (Mar. 1, 1935, to Feb. 28, 1936)	February 1936	February 1934

Figure 12 shows that the type of variation observed in 1933 was repeated in 1935, when the minimum occurred at 11^h and the maximum at 2^h

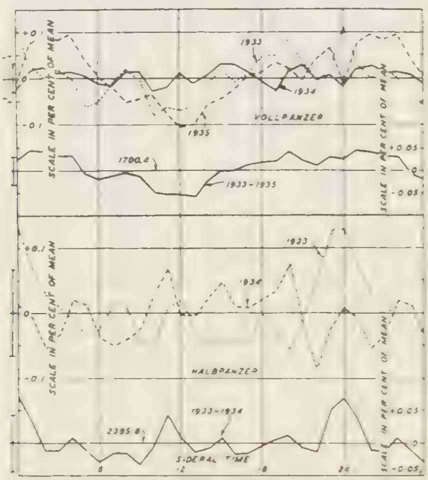

FIG 12—SIDERAL-TIME DIURNAL-VARIATION COSMIC-RADIATION INTENSITY VOLLPANZER AND HALBPANZER CAPETOWN

sidereal time. The curve for 1934 does not show any significant variation.

The combined results for the three years are shown in the second curve of Figure 12 which is roughly sinusoidal. It has an amplitude of 0.05 per cent of the mean intensity, with maxima and minima at 24^h and 12^h, respectively. The average root-mean-square deviation of a single hourly plot is 0.03 per cent.

The smallness of this sidereal-time effect and the fact that the original observations have not been corrected for temperature-effects must raise considerable doubt as to its significance.

The method employed in obtaining the sidereal-time curve does however offer a reasonable chance of eliminating those solar-time effects which can give spurious sidereal-time effects on account of the lag of four minutes per day between the two, provided that seasonal changes on the solar-time effect are inconsiderable. That this is actually the case seems to follow from a comparison of the present results with those obtained in Europe. The curve under discussion has a phase which agrees with that of the solar-time curve for the month of September. If it were spurious, and due to a residual solar effect, its phase in the Northern Hemisphere would be expected to be shifted so that it agreed with the solar-time curve for the month of March. In other words *spurious* sidereal-time effects in the two hemispheres should differ in phase by 12 hours. In actual fact, however, the sidereal-time curve obtained by Hess and Steinmaurer on the Hafelekar and recently reported on by Illing[15] shows nearly the same phase as that of Figure 12. Their results for the years 1932, 1933, and 1934 show a maximum at 17^h and a minimum at 10^h sideral time, the amplitude being 0.3 per cent of the mean.

This similarity between the Northern and Southern hemispheres is again in evidence when the *HP*-results are considered. The *HP*-observations for 1934 and 1935 are shown in the third part of Figure 12 while the combined curve for these two years is below. The total number of observations is smaller than in the case of *VP*, the combined two-year *HP*-curve comprising about the same number of hours as a single year of *VP*. The curve shows a maximum at 24^h and a smaller maximum at 11^h with minima at 6^h and 16^h, respectively. The results of the analysis of Illing[15] for the Northern Hemisphere show a similar double maximum in the case of *HP* (at 17^h and 7^h sidereal time) and minima at 2^h and 15^h.

On the assumption of a uniform distribution of the cosmic radiation in space, Compton and Getting[16] have shown that a sinusoidal variation of intensity is to be expected to arise from the galactic rotation. The amplitude of the variation is calculated by them to be of the order of 0.05 per cent with a maximum at 20^h and a minimum at 8^h local sidereal time. The present data, combined with those obtained by Hess, Steinmaurer, and Illing in the Northern Hemisphere are in accord with this suggestion. It is however necessary to continue the observations over a much longer period and in the case of the station at Capetown to ensure absence of the inner temperature-effect before the suggestion can be regarded as established.

Summary

Continuous observations have been made in Capetown, South Africa, during the years 1933, 1934, and 1935 of the intensity of the cosmic radiation with an ionization-instrument designed by Steinke.

(1) The mean coefficient of the barometer-effect is -0.352 *mJ mm* (0.216 per cent per mm) inside 10cm of lead (*VP*) and -0.81 *mJ mm* with top of lead shield removed (*HP*). The coefficients show no significant variation with season or year.

[15] Terr. Mag., **41**, 185-191 (1936).

[16] A. H. Compton and I. A. Getting, Phys. Rev., **47**, 817-821 (1935).

(2) The absolute value of the intensity under 10 cm of lead (*VP*) in Capetown is 1.634 ± 0.016 *J* at standard atmospheric pressure.

(3) The absolute intensity in Königsberg, Germany, measured on the same instrument is 0.12 *J* higher.

(4) The annual means of intensity show no variation greater than one part in 1000.

(5) A seasonal fluctuation of amplitude 0.5 per cent is observed, with a maximum in the southern winter and a sharp minimum in January. This can be partly accounted for by an outer temperature-coefficient of -0.12 per cent per degree C (*VP*).

(6) An apparent variation with solar time of amplitude 0.2 per cent with a maximum at about 14^h is observed. When corrected for inner and outer temperature-effects this indicates a true solar-time effect of the same phase and of amplitude 0.3 per cent.

(7) A sinusoidal sidereal-time variation of amplitude 0.05 per cent is indicated, the maximum for *VP* occurring at 24^h sidereal time. For *HP* maxima at 24^h and 11^h are observed.

We wish to offer our thanks to Dr. E. Steinke who, in addition to testing the instrument, arranging for its despatch and for the reduction of observations at his bureau, has helped us materially with his advice on various questions. We have also gratefully to acknowledge the financial support of the Carnegie Corporation of New York and South African Research Grant Board. We wish to thank J. Linton and G. Lang for valuable assistance in the running of the instrument and B. Gotsman for help in reducing the data. One of us (J. G.) is indebted to the University of Cape Town for a research stipend.

University of Cape Town,
Capetown, South Africa

INFLUENCE OF POLLUTION ON POTENTIAL GRADIENT AT APIA

By H. B. Sapsford

The general results of research on the diurnal variation of potential gradient lead to the conclusion that its form at any station is due to a local variation superimposed on the single universal-time oscillation which was discovered by S. J. Mauchly [see 1 of references given at the end of the paper]. It has been pointed out that the local variation in the potential gradient must be due to changes in the atmosphere immediately surrounding the station [2]. Further it has been agreed that the conductivity is the chief factor in determining the gradient. J. G. Brown has also suggested that the conductivity at any time is dependent, in turn, upon the formation of small ions and the number of nuclei present at that time, the latter being a greater cause of variation in the conductivity than the former. At land-stations these nuclei are mainly in the form of pollution-particles such as dust and products of combustion and decaying organic matter.

Now Dr. G. S. Simpson has explained how the diurnal variation of atmospheric pollution is due to the combined effects of the variation in the rate at which pollution is diffused upward by convection and the variation in the rate of production of smoke [3]. Also F. J. W. Whipple has shown that there is a relation between atmospheric pollution and potential gradient [3]. These results have been used by F. J. Scrase to explain the double oscillation in the potential-gradient curve at Kew [4]. J. G. Brown has gone further and has shown that there is a similarity among the local variations at 22 different stations, due to the influence of the cycle of turbulence, convection, and subsidence, which takes place over land on every clear day [2]. This similarity has been obtained without making any allowance for other local factors, and it is possible that a closer study of particular effects at the individual stations might lead to an even more uniform classification of the types of local variation.

The form of diurnal variation at Apia is in general agreement with the theories which have been mentioned above. However, it is intended in this paper, to show that pollution in the form of combustion-products is the local factor in Samoa which exerts the strongest influence on the potential gradient at the times of maxima. Furthermore, attention will be drawn to the fact that the wind-direction has a controlling effect on the maxima at this station.

At this stage it is necessary to describe briefly some of the habits of the natives since domestic fires are the only important source of smoke in Samoa. The following statements concerning native habits have been verified by questioning several natives individually and C. G. R. McKay, Secretary of Native Affairs, has certified that they are correct.

From Monday to Friday the Samoans kindle fires mainly for the purpose of boiling water and preparing boiled foods. This fire-lighting is carried on during the first few hours after sunrise and again for a few hours about sunset and it produces a considerable amount of smoke which can be seen clearly as a low haze when looking from the coast

towards the base of the hills. During the week a few large fires also are made at about 10 or 11 a. m. for the purpose of heating stones for the Samoan umu (ovens). These, however, are not lit on any special day during the period Monday to Friday, the lighting depending on the requirements of the various native families and on the available food supply. It seems that the early morning domestic activity during the period Monday to Friday is limited to villages in and around Apia. The other native habits mentioned in this paper are quite general.

The domestic routine is more standardized on Saturday and Sunday and is different from that on any day during the remainder of the week. This is due to the fact that the Samoans are strict sabbatarians during the daylight hours of Sunday. On Friday firewood is collected for the week-end and on Saturday morning almost every Samoan family lights a large fire in order to heat stones for the Samoan umu. Most of these fires are lit during the first few hours after sunrise and much more atmospheric pollution in the form of smoke is caused by them than by the fires on any of the five preceding mornings. The cooking activities on Saturday evening are not very different from those on other evenings but Saturday afternoon is the usual time for the burning of fallen leaves, twigs, cut grass, and any general rubbish in order to have the houses and surroundings clean for Sunday. It may be expected that this general incineration results in Saturday afternoon being that on which maximum pollution in the form of smoke occurs and visual observations appear to confirm this.

Special fires for Sunday are built, but not lit, on Saturday night. These fires are all lit at about the same time (daybreak) on Sunday morning and the simultaneity of lighting results in there being a greater concentration of pollution for a few hours on that morning than at any other time during the week. This increase of pollution in the form of smoke on Sunday morning is so marked that the visibility in Apia, over the harbor and lagoon is often considerably reduced by it. When the early morning cooking is finished it is customary for the natives to refrain from all other work; thus practically no fires are lit on Sunday evening. There is therefore a minimum of pollution from domestic fires at that time.

To recapitulate it may be stated that in Samoa as far as pollution in the form of combustion-products is concerned, there is a maximum for the week on Sunday morning and a minimum on Sunday afternoon. Also there is a greater amount on Saturday morning and again on Saturday afternoon than at the corresponding times on any of the five preceding days. On other days there is a concentration of pollution for a few hours at sunrise and again at sunset.

It was considered that the concentration of smoke on Sunday morning and the absence of it on Sunday evening would have an effect on the potential-gradient curve for that day of the week. The 264 days of character 0 (complete days free from negative potential) which have been recorded since September 1933 were grouped according to the days of the week and the means of the average hourly values for each day were computed to test this. It was apparent that Sunday was an exceptional day as had been expected. In order to illustrate this, and at the same time to show the order of consistency which exists among the other days of the week, the six days, Monday to Saturday, have been grouped

and the hourly means of the average hourly values for this period have been subtracted from those for each day of the week. The differences are shown in Table 1. All differences of ten or more volts per meter have been printed in bold-faced type in Table 1. It will be noticed that there is a high order of consistency throughout the week except at the times of the maxima of potential gradient. An examination of the values at the times of the morning maxima shows that the largest positive differences occur on Sunday and that those on Saturday are greater than on any of the five preceding days. The evening values show that the only large positive differences at that time are on Saturday while the only large negative differences are on Sunday. Thus it is seen that at the times of maxima of potential gradient the variation of the maxima during the week-end corresponds exactly with the variation in the amount of pollution from domestic fires.

To illustrate the point further three curves have been plotted in Figure 1. They are diurnal-variation curves of potential gradient for Sunday, the six-day period Monday to Saturday, and the whole week. The high maximum on Sunday morning and the low suppressed maximum on Sunday evening make it evident that there is some unusual variation in the local influence on that day. It is contended that the local factor is the variation in the amount of pollution. If it is agreed that the variations in the maxima of potential gradient during the week-end are due to the influence of pollution, then it is reasonable to assume that the smoke which is present on every morning of the week causes part of the usual morning rise in potential.

The reason why the wind-direction at Apia plays a significant rôle in controlling the maxima of potential gradient now becomes obvious in view of the foregoing conclusions. The Observatory, being situated at the end of a peninsula which juts out from the main coast into the lagoon, is exposed directly to the winds off the sea which predominate between 10^h and 19^h (165° west meridian time) on days of electric character 0. When the mass of air associated with these winds reaches Samoa it has traveled long distances over the Pacific Ocean and it is unlikely that they convey pollution other than fine particles of salt. During the evening and the early morning land-winds predominate and these are contaminated by the pollution which originates on the Island.

To prove the predominance of the land-winds at night and of the winds off the sea during the day the wind-directions were examined on the same 264 days that were used in the investigation of the pollution-effect. The frequencies of mean wind-directions for each hourly period, expressed as percentages of the total number of observations (256 complete days), have been tabulated in Table 2. The southerly night-winds and easterly day-winds are conspicuous. Now the northern coast of the island on which this Observatory is situated trends almost east-southeast and west-northwest. Therefore all winds from southeast, through south, to west have been considered as land-winds and all those from northwest, through north to east, as sea-winds. Frequencies of land-winds and of winds off the sea have been obtained by adding values from Table 2 in accordance with this grouping. East-southeast and west-northwest winds have not been included since they blow from directions parallel to the coast-line. Curves for these frequencies have been plotted in Figure 2 and the

Table 1—*Differences of mean hourly values of potential gradient in volts per meter, Apia Observatory, September 1933 to December 1936*
(Mean values for each week day minus mean values for the six-day period, Monday to Saturday)

Day	165° west meridian hour																								No. of days
	0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12	12–13	13–14	14–15	15–16	16–17	17–18	18–19	19–20	20–21	21–22	22–23	23–24	
Mon.	−6	−6	−5	−6	−4	−5	−9	−1	**−20**	**−18**	−4	−1	−2	−4	−2	−1	−2	+1	+7	+1	+7	+6	+2	−1	37
Tues.	**−11**	−9	−7	−1	−4	−5	−3	−7	**−14**	−5	+1	0	0	−1	−1	−1	−2	−4	+1	−7	0	−2	−2	−4	30
Wed.	+1	+3	+3	−1	−2	+1	+2	+9	**+11**	−5	−1	+1	−2	+4	+4	−1	−2	−1	−4	−3	−6	−8	−3	+3	42
Thur.	+6	+2	+2	+5	+3	0	+4	+9	**+10**	+8	+1	−1	−1	0	+1	+2	+1	0	−7	0	**−10**	−7	+2	+2	39
Fri.	+2	+4	0	+2	+7	+3	+2	**−10**	**−21**	−5	−4	0	0	−3	−3	−2	+1	−2	−1	−8	−9	−2	+4	+4	35
Sat.	+6	+4	+4	+2	+2	+4	0	−4	**+29**	**+19**	+8	−1	+2	+1	−1	0	+1	+1	+5	**+13**	**+15**	**+15**	+1	−3	41
Sun.	+7	+3	0	+2	−2	**+11**	**+87**	**+110**	**+68**	**+21**	+2	1	−4	0	0	−3	−5	−6	**+27**	**−63**	**−51**	**−29**	**−13**	**−10**	40

Table 2—*Frequencies of wind-directions (expressed as percentages of total number of observations) for each hour on days of electric character 0 for 256 complete days, Apia Observatory, September 1933 to December 1936*

Wind-direction	165° west meridian hour																							
	0 1	1–2	2–3	3–4	4 5	5–6	6 7	7–8	8–9	9–10	10–11	11–12	12–13	13 14	14–15	15–16	16–17	17–18	18–19	19–20	20 21	21 22	22–23	23–24
Calm	0	1	1	1	0	0	0	1	3	3	1	0	0	0	0	0	1	0	1	1	0	0	0	0
N	0	0	0	0	0	0	0	0	0	0	2	2	3	2	1	1	2	1	0	0	0	0	0	0
N N E	0	0	0	0	0	0	0	0	0	3	5	5	2	3	4	5	1	1	0	0	0	0	0	0
N E	0	0	0	0	0	1	0	0	2	7	6	6	5	4	4	5	4	2	1	0	0	0	0	0
E N E	0	1	0	0	0	1	1	1	3	10	15	16	20	19	18	16	13	10	4	2	2	1	0	1
E	3	2	2	2	3	2	2	2	7	45	53	56	55	56	56	56	53	51	33	10	4	4	6	4
E S E	10	9	7	6	6	5	5	8	25	19	9	6	6	6	6	6	11	18	33	25	19	13	14	15
S E	14	15	17	18	17	17	17	20	22	2	1	0	2	3	2	3	2	2	8	32	26	23	21	14
S S E	14	14	14	11	13	12	14	12	6	0	0	1	0	0	0	0	2	2	5	9	17	17	17	17
S	41	39	38	36	35	35	36	33	18	2	1	1	1	0	0	1	1	2	3	12	23	32	32	37
S S W	15	15	15	22	19	22	20	16	5	0	1	0	0	0	1	2	3	4	3	4	7	7	7	10
S W	3	3	4	4	5	4	2	4	3	2	0	1	1	1	1	0	1	0	2	2	2	2	1	2
W S W	0	0	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	1	1	2	0	0	1	0
W	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	0	0	0	0	0
W N W	0	0	0	0	0	0	0	1	1	1	0	0	0	1	1	0	1	1	1	0	0	0	0	0
N W	0	0	0	0	0	0	0	0	0	0	2	1	2	2	2	3	1	2	1	0	0	0	0	0
N N W	0	0	0	0	0	0	0	0	0	3	2	3	2	2	2	2	1	1	0	0	0	0	0	0
Var.	0	1	2	0	1	1	1	2	5	3	2	2	1	1	2	0	2	1	2	1	0	1	1	0

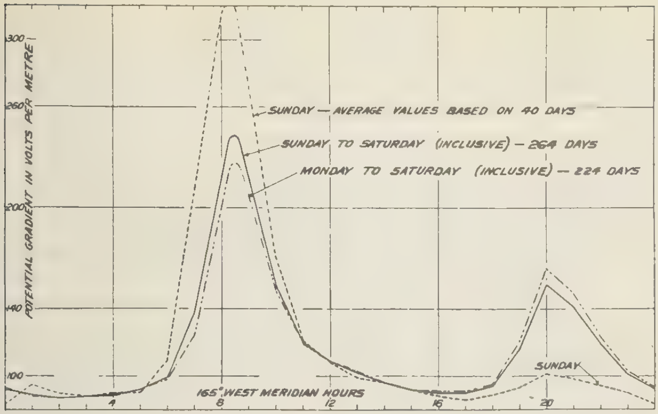

FIG. 1—CURVES ILLUSTRATING UNUSUAL DIURNAL VARIATION OF POTENTIAL GRADIENT ON SUNDAY AT APIA

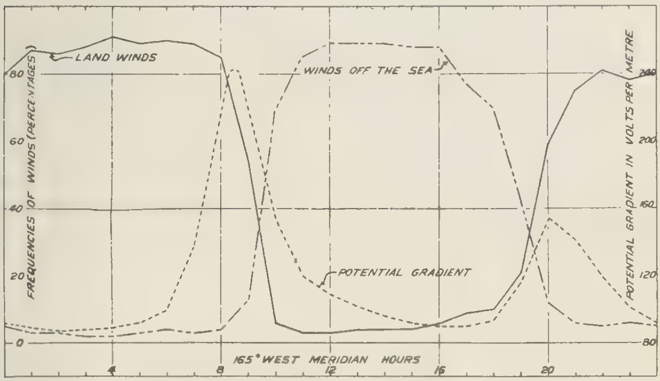

FIG. 2—CURVES ILLUSTRATING DIURNAL VARIATION OF FREQUENCIES OF WINDS OFF THE SEA, FREQUENCIES OF LAND WINDS, AND POTENTIAL GRADIENT

diurnal-variation curve of potential gradient has been plotted in the same Figure.

It will be noticed how the potential gradient builds up in the morning and reaches a maximum while the land-wind is blowing. This occurs in the period during which the rate of smoke-production is increasing. There is a considerable and rapid drop in potential with the change of wind-direction and it is contended that this is due to the relatively clean air associated with the sea-winds suddenly dispersing the pollution carried by the land-wind. The graph also shows that the potential gradient increases again at night when the polluted land-wind replaces the sea-wind. Smoke is being produced over the flat coastal regions and near the base of the hills before the change in wind occurs, and it collects in the more sheltered spots distant from the coast. Consequently the land-breeze at night is highly polluted at the time of onset and this fact accounts, in part at least, for the rapidity of the increase in potential gradient at that time.

Thus it is seen that the influence of the change in wind-direction is such that it results in a more rapid decrease of potential gradient in the morning and in a more sudden rise in the evening than would otherwise occur. The curves in Figure 2, which are based on average hourly wind-directions and average hourly values of potential gradient, illustrate the relation between the two elements quite well. However, the effect may be seen more clearly in another paper on this subject in which individual traces of wind and potential gradient are compared [5].

Although the change in wind-direction modifies the shape of the diurnal-variation curve and the influence of pollution contributes largely to the formation of the maxima, it is realized that there are other factors which affect the potential gradient throughout the day. For instance, the complete morning maximum is probably due to the combined effects of pollution and other local factors superimposed on the universal variation, and Figure 1 shows that there is an evening maximum even on Sundays. Therefore it may be inferred that after allowing for the effects mentioned in this paper the diurnal-variation curve would still be of the same general form, but would show a smaller daily range of potential gradient. The influence of very regular phenomena such as the cycle described by J. G. Brown together with the unitary variation probably accounts for the shape of the modified curve.

It is not intended to discuss here the relative effects which the various factors have on the diurnal variation. The primary object of this paper is to point out the important influence of pollution on the maxima of potential gradient at Apia and to offer further evidence in support of the previously published statement that the wind-direction has a controlling effect on the maxima at this station [5]. In conclusion I should like to thank the Acting Director, W. R. Dyer, and other members of the Observatory staff for their assistance while preparing this paper.

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[1] S. J. Mauchly, Res. Dept. Terr. Mag., **5**, 387-424 (1926).
[2] J. G. Brown, Terr. Mag., **40**, 413-424 (1935).
[3] F. J. W. Whipple, Q. J. R. Met. Soc., **55**, 351-361 (1929).
[4] F. J. Scrase, London, Met. Office, Geophys. Mem., No. 60 (1934).
[5] H. B. Sapsford, Terr. Mag., **41**, 29-36 (1936).

Apia Observatory,
Apia, Western Samoa, April 5, 1937

THE FUNDAMENTAL THEOREM OF APPLIED GEOPHYSICS

By H. Löwy

In all methods of geophysical prospecting, the attempt is made to ascertain the depth and extent of deposits (ore, oil, ground-water) by means of certain measurements made on the Earth's surface. The question as to whether and under what conditions such an analysis may be made in a unique manner constitutes the fundamental problem of applied geophysics.

The problem requires a separate solution for each method. In 1927, I published a solution for the electrodynamical method.[1] As for the other geophysical methods, in the absence of a solution, recourse is had to a rule formulated by Professor A. O. Rankine[2] as follows: "Underground structures, agreeable to the geophysicist's experience, have to be taken as hypotheses, and tested by calculation and comparison with the data provided by surface-observations." It is a very laborious and uncertain procedure. Even if one, by good luck, succeeds in divining a hypothetical underground structure which is in ideal agreement as respects the calculated and observed values, yet there is no certainty that this corresponds with reality. The physical values at the surface are uniquely determined by the underground structure but the inverse theorem—namely, that the underground structure may be uniquely ascertained from physical measurements made at the surface—does not necessarily follow. Indeed, it is not upon physics nor upon mathematics (however imposing some of the displays of the latter) but upon geology that the successful interpretation of geophysical measurements usually depends. The hypothetical structure must be "agreeable to the geologist's experience." This is, according to Rankine "the geologist's selection rule." It signifies no guide in the terra incognita, but, on the contrary, the exclusion of it. Until the fundamental problem is solved, the geophysicist will be obliged to work only in geologically known country.

The mathematical treatment of the inverse problem requires that the term "underground structure" be replaced by the term "spatial distribution of physical constants of material." The demonstration of the theorem, therefore, implies the possibility of only an *indirect* analysis of the underground, that is, the possibility of ascertaining not ore, nor oil, nor ground-water, but only a certain distribution of some physical constants of matter. The inverse theorem is only a part of the fundamental theorem. The demonstration of the latter requires the investigation as to whether the deposits of ore, oil, etc., are uniquely characterized by the values of the material-constants and it is only then that a direct analysis of the underground is possible.

In his presidential address to the British Association in 1932, Professor Rankine said that "in all geophysical methods, interpretation is necessaily indirect." This characterizes the view at present generally held in the case of most geophysical methods but which is not necessarily valid. For

[1]Naturw., **15**, 921-928 (1927).
[2]Nature, **130**, 421-424 (1932).

the gravitational, the seismic, and the magnetic methods neither the fundamental nor the inverse theorem has been demonstrated. Hence, *these methods can be applied only in geologically known regions.*

L. B. Slichter[3] has recently formulated the inverse theorem for the electric-resistivity method. The mathematical solution found by R. E. Langer (University of Wisconsin) shows that, in the case of horizontal structures, "knowledge of the surface-potentials alone suffices to determine uniquely the variation of conductivity with depth."

In the case of the resistivity-method, electric currents are introduced into the ground and the resistivity of the latter must, accordingly, be relatively small. The soil-resistivity range, in which the method can be used, is according to J. Koenigsberger[4] 10^4 to 10^5 ohm-cm. A. B. Broughton Edge and T. H. Laby in their book "The principles and practice of geophysical prospecting" (Cambridge, University Press, 1931) have indicated a greater range 10^2 to 10^6 ohm-cm, which seems to mark the utmost limits attainable by neglecting the prospecting of the greater depths and by using high voltages impracticable in field-work. The resistivity-method, therefore, can be applied only in humid soil. In such soil the resistivity of rocks varies between 50 and 10^6 ohm-cm (*cf.* Broughton Edge and Laby, *loc. cit.*, p. 10). Direct location of a certain deposit is possible if its resistivity does not coincide with that of humid country rock or other deposits. The following interesting resistivity-values are taken from the book by Broughton Edge and Laby.

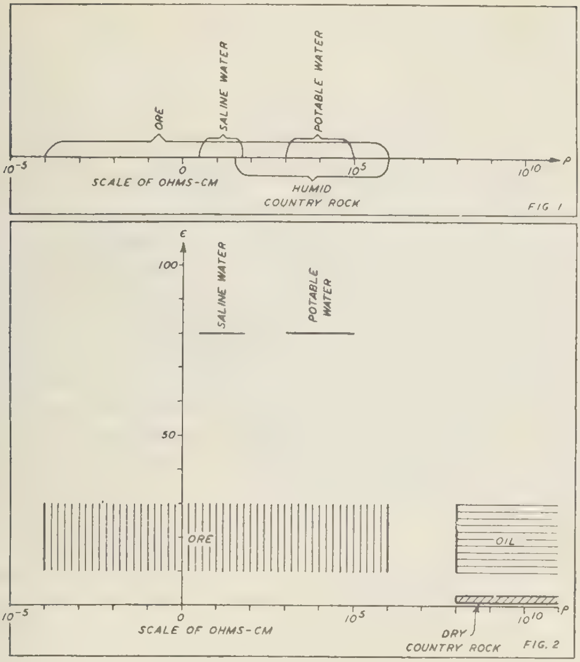
Material	Resistivity i ohm-cm
Ore minerals	10^{-4} to 10^6
Normal water (potable)	10^3 to 10^5
Saline waters	
1 per cent sodium chloride	75
5 " " " "	15
10 " " " "	8
20 " " " "	5
Humid country rock	50 to 10^6

In Figure 1, I have indicated the values of the resistivity. It may be seen that in humid country it is possible, using the resistivity-method, to determine directly the location of ores whose resistivity is less than 1 ohm-cm. The direct location of ground-water (potable or saline) is however, impossible as is shown in Figure 1. In humid country, according to Professor Koenigsberger, one is obliged, before applying the method, to study, for every new locality, at one or two successful borings in the vicinity, how the existence of potable water is disclosed by geophysical measurements[5].

I will now discuss the fundamental theorem of the electrodynamical method and outline the main points of the demonstration I have given[1]. The method makes use of electric oscillations and can therefore be employed only in arid regions. The dry country rock of these regions by virtue of its dielectric character represents the "visible space" which is illuminated by the electric waves. Thus we "see" what may be in that space.

The fundamental theorem is based on a geophysical fact which I noted in 1910[6], namely, that the electric qualities of rocks are not de-

[3]Physics, **4**, 307-322 (1933).
[4]Beitr. Geophysik, Ergänzungshefte, **3**, 463-525 (1933).
[5]Beitr. Geophysik, Ergänzungshefte, **3**, 493 (1933).
[6]Physik. Zs., **11**, 697-705 (1910).



termined by their petrographical and geological character, but by their water-content, and that the electric constants of the various rocks approach, with diminishing moisture, the same limiting value of an ideal insulator. This fact has now been verified by the laboratory experiments of R. L. Smith-Rose[7] and by my own field-measurements in the Colorado Desert[8], in the Algerian Sahara[9], and in Egypt and Palestine[10]. There corresponds to the n-layer problem of the resistivity-method a much simpler problem of the electrodynamic method, namely, that the n layers of the dry country rock, from the electrical point of view, may be regarded as one dielectric layer. If there exist in the dielectric country rock some conducting layers, only one (the uppermost) need be considered, according to the Faraday's cage-effect. Thus the variety of underground structures is reduced to the geometrical configuration of a conducting surface with a dielectric cover of varying thickness d and varying values of the dielectric constant ϵ and conductivity σ.

At the Earth's surface, the capacity C and resistance R of a ground-antenna are measured. These physical quantities are determined in a uniform manner by the underground structure, that is, C and R are uniform functions of d, ϵ, and σ, given by the formulas of M. Abraham and A. Sommerfeld[1]. The inverse theorem is based on the fact that the

[7]J. Inst. Electr. Eng., **74**, 221-237 (1934).
[8]Physik. Zs., **32**, 337-345 (1931).
[9]Zs. Ges. Erdk., 204 (1933).
[10]Naturw., **23**, 259 (1935).

functions are monotonic. From the monotonic form, there results directly the unique inversion, that is, the possibility of uniquely deducing the spatial distribution of electric constants from the surface-measurements.

There remains the question whether the deposits are characterized by the electrical constants in a unique manner. The restrictions to the applicability of the resistivity-method (Figure 1) do not exist for the electrodynamic method. When, for instance, two horsemen meet in a field-path, they can avoid a collision by turning aside from the one-dimensional path into the two-dimensional field. Such a way out is also accessible in the case of the electrodynamic method, in which not only the resistivity ρ, but also the dielectric constant ϵ, is measured. Figure 2 represents the field of the $(\epsilon-\rho)$ values. The value-ranges for dry rock, ore, potable and saline water are determined according to the data of Smith-Rose, McGarva Bruckshaw, Broughton Edge, and Laby. The delimitation of the oil-range is based on a hypothesis[1] I have proved in the oil-fields of Southern California[8]. It is seen that the ranges of the different deposits neither overlap each other nor are overlapped by the range of the dry country rock. Hence, in arid country, the direct location of ore, oil, saline and potable ground-water is possible with the aid of the electrodynamic method[11]. In general, we may say that the fundamental theorem guarantees the independence of geophysics and is the only sure guide to the terra incognita.

Cairo, Egypt, July 1936

[11] A detailed demonstration of the fundamental theorem will be published in the Proceedings of the Mathematical and Physical Society of Egypt, 1937.

THE EFFECT OF OVERCAST SKY UPON THE LOCAL DIURNAL VARIATION OF THE EARTH'S ELECTRIC FIELD

By Joseph G. Brown

In a previous paper[1] a method of obtaining the local diurnal variation of the Earth's electric field was adopted and a theory to account for the local variation was proposed. In a later paper[2] it was shown that the greatest amplitudes of the local variation occur in clear weather with calm nights and only gentle variable winds during the daytime. Under these conditions, according to the theory, the processes of turbulence, convection, and subsidence have their maximum effect in varying the density of nuclei of condensation in the lower atmosphere. On the other hand, continuous wind was shown to be associated with much smaller amplitudes of the local variation. The inference was drawn that continuous wind, due to its turbulent action at the surface, keeps the nuclei stirred up to such an extent that the effect of turbulence and convection caused by surface-heating during the daytime and the effect of subsidence at night are very much reduced.

It seems probable, if the theory of the local variation is correct, that anything which reduces the amount of heating at the surface will reduce the amplitude still more. To test this conclusion it was decided to compare the local variation during clear weather with that during weather with overcast sky. To make the comparison reliable it was necessary to have the wind-conditions as nearly the same as possible for both types of weather. The only long enough series of potential-gradient measurements with wind- and sky-data available here is that of the Ebro Observatory at Tortosa, Spain. From these records 50 electrically quiet days with not more than one hour of sunshine and with only light, variable winds were selected from the period October to March inclusive. The mean local diurnal variation was obtained by the method referred to above and compared with that for 50 clear days with similar winds from the same period. As will be seen from Figure 1 the forms of the curves are quite similar but the mean amplitude on overcast days is only about half of that on clear days. This result is in complete harmony with the proposed theory of the local variation.

As a further test, 50 overcast days with continuous wind averaging 400 km day, were compared with 50 clear days having continuous wind of similar mean speed and from the same period. Figure 2 (*A* and *B*) shows the two mean local variations. The forms of the curves are again quite similar in this comparison, but the amplitude of the evening maximum on overcast days is only about two-thirds of that on clear days. This result seems to indicate that wind is the main factor in reducing the amplitude of the local variation but even with considerable speed the effect of overcast sky is still noticeable.

[1]Terr. Mag., **40**, 413-424 (1935).
[2]Terr. Mag., **41**, 279-285 (1936).

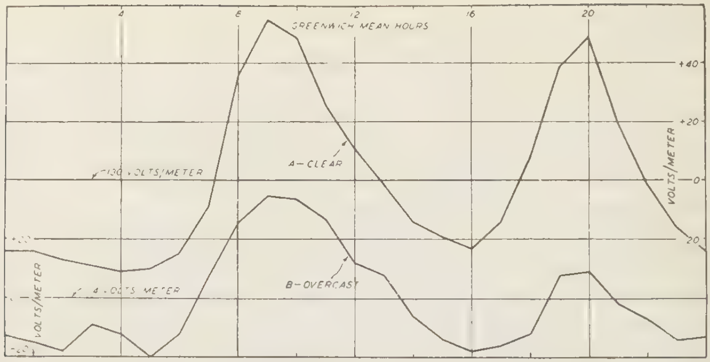


FIG 1—LOCAL VARIATIONS, LIGHT VARIABLE WIND, EBRO OBSERVATORY

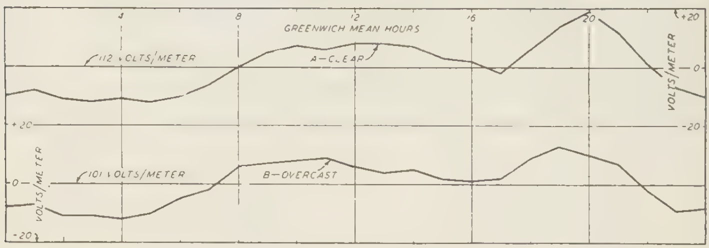


FIG. 2—LOCAL VARIATIONS, CONTINUOUS WIND, EBRO OBSERVATORY

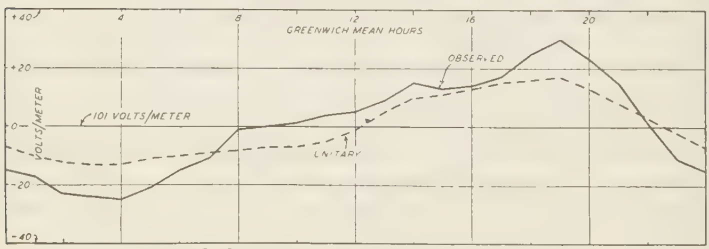


FIG. 3—OBSERVED AND UNITARY VARIATIONS, EBRO OBSERVATORY

In order to show how closely the observed variation approaches the unitary variation on windy, overcast days, these two curves are reproduced in Figure 3. The local variation of Figure 2*B* is of course the difference between the two curves. The fact that the local variation in this extreme case comes out with the same characteristic maxima and minima as on clear quiet days seems to show that the method of obtaining the local variation is reliable.

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EARTH-CURRENT VARIATIONS WITH PERIODS LONGER THAN ONE DAY*

By W. J. Rooney

Abstract—Examination of the earth-current records from Tucson and Huancayo shows that the daily mean values recorded on characteristically disturbed and calm days differ consistently by a small amount. This suggests that a part of the current flowing during disturbances or magnetic storms is unidirectional for the day or longer and is the first definite indication of a component in earth-currents with period greater than one day. The magnitude of the effect is small, not more than a few per cent of the range of diurnal variation at a given station. The direction of flow indicated is to the north and east at Tucson and to the south and east at Huancayo. These directions are consistent with those noted in the diurnal variations but they may be modified by local geological features. The reversal of direction of the northward component is also a feature of the diurnal variations when the stations considered are on opposite sides of the equator. The potential gradient due to earth-current flow is so small at Watheroo, in proportion to the large and irregular contact-potentials occurring there, that the Watheroo records are not conclusive on this point. In so far as they have any significance, the results are in agreement with those at Huancayo and consistent with the preferred direction of current-flow found in the diurnal-variation records. A wider distribution of stations and a more accurate quantitative measure of the effect is necessary before attempting to suggest a system of current-circulation consistent with these results.

That the greater part of the potentials recorded on earth-current lines is due to electrochemical potentials at the electrodes can be readily demonstrated. Many attempts have been made to minimize these electrochemical potentials by the use of rather elaborate electrodes of one type or another in place of simple metallic ones such as the grids of pure lead wire used in the installations at Watheroo, Huancayo, and Tucson. It is sometimes possible, using certain reversible electrodes—metallic copper in copper-sulphate solution, for instance—to reduce the absolute values of potential recorded between two given points in the ground, and it should be possible, theoretically, to keep such electrodes more constant than the simple metallic ones. However, it is found in practice that the advantages of reversible electrodes for earth-current work are not readily realized. In order to make contact with the ground there must inevitably be a slow seepage of the electrode-solution into the ground about the electrode. This results in a constantly changing electrode-environment and the constancy of such an electrode turns out to be pretty much a myth.

So, because of the limitations of any electrode so far devised, investigations dealing with earth-currents must be largely restricted to the study of the variations in the recorded potentials such as the diurnal variation or the aperiodic fluctuations closely related to magnetic disturbances. It is possible with our present electrodes to keep the mean values recorded at most stations fairly constant over considerable periods of time and so permit accurate determination of these short-period variations. It is further possible, by the use of multiple-recording systems using different lengths of line and separate pairs of electrodes in recording a given component, to demonstrate the extreme unlikelihood of the ex-

*Presented at annual meeting, Section of Terrestrial Magnetism and Electricity, American Geophysical Union, held April 28, 1937, at Washington, D. C.

istence of any "constant component" or "unvarying part" in earth-current flow[1].

But it must be conceded that there may exist, in addition to storm-fluctuations and the regular diurnal variation with its components of periods up to 24 hours in length, slower variations with periods longer than a single day. The detection and evaluation of such long-period variations must be attempted with caution because of the changes—primarily connected with changes in the amount and concentration of solutions in the soil near the electrodes—which are known to occur in the electrochemical part of the recorded potentials. Slow changes in contact-potentials cannot be entirely eliminated and they can be, and often have been, mistaken for variations in earth-current flow. For this reason investigations into the existence and magnitude of slow variations in earth-currents can best be made on a long-line installation since the masking electrochemical potentials, being largely independent of the length of the line, constitute a much smaller part of the total recorded value when the lines are long.

The longest lines currently in use for earth-current measurements are those at Tucson, Arizona. There the northerly line is 56.8 kilometers long, and the eastward line 93.9 kilometers[2]. The Tucson installation, operated cooperatively by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, the United States Coast and Geodetic Survey, the Bell Telephone Company, and the Mountain States Telephone and Telegraph Company, has been recording continuously since March 1931, and the records from that station will be given first consideration in the following discussion. Evidence from the records from the short-line installations at the Huancayo and Watheroo Magnetic observatories of the Department of Terrestrial Magnetism bearing on the subject of slow variations is also included.

During the first five years of operation at Tucson the mean monthly values of potential recorded on the northerly line, length 56.8 km, direction north 19° 33′ east, ranged from -72 to $+23$ millivolts, while the extreme range in the daily means was a little less than 300 millivolts. Dividing these values by the length of the line gives -1.1 to $+0.4$ mv/km for the range of the monthly means and a little over 5.0 mv/km for the range in the daily means. Corresponding values for the eastward line, length 93.9 km, direction east 0° 29′ north, are -1.0 to $+0.5$ mv/km for the monthly means and about 3.0 mv/km as the range in the daily means. The manner in which the daily and monthly means varied during this period is shown in Figure 1. The solid curves give the monthly means while the dotted curves show the highest and the lowest daily mean values recorded during each month. To the right of the curves the average range of diurnal variation is shown for each component; this is about 5.0 mv/km for the northerly component and 1.7 mv/km for the eastward component.

With reference to the monthly means, two facts are worthy of note. First, both the magnitude and the variation in the monthly means are small in comparison to the diurnal variation. And second, the chief variation these means exhibit is a slow irregular drift. A slow drift of this character is often found in the electrochemical potentials between

[1]W. J. Rooney, Terr. Mag., **37**, 363-374 (1932).
[2]W. J. Rooney, Terr. Mag., **40**, 183-192 (1935).

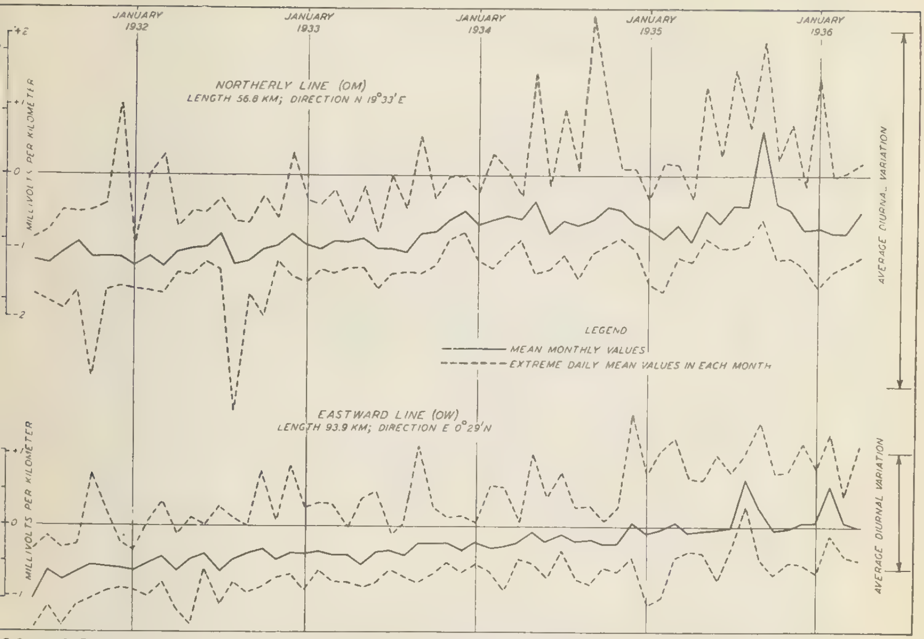

FIG. 1—MONTHLY MEAN VALUES OF POTENTIALS RECORDED ON EARTH-CURRENT LINES AT TUCSON, ARIZONA, JUNE 1931 TO APRIL 1936, WITH HIGHEST AND LOWEST DAILY MEAN VALUES RECORDED IN EACH MONTH

pairs of electrodes which are not affected by large and rapid changes in soil-moisture. Considering next the dashed curves, it will be noted that the extreme range in the daily means, when expressed in millivolts, is not greatly different for the two components. For the northerly component this range is just about equal to the diurnal variation and it is a little less than twice the much smaller diurnal variation in the case of the eastward component.

Curves similar to those in Figure 1, showing the variation in the monthly and daily mean values of potential recorded on certain of the lines at Huancayo and Watheroo, and their magnitude, absolute and in relation to the diurnal variation, are given for comparison in Figures 2 and 3. The monthly mean values at Huancayo, recorded on lines between two and three km long, are somewhat smaller in magnitude than those at Tucson. They vary more erratically from month to month and show some indication of seasonal change. The large seasonal change on the northward line at Watheroo, length 2.0 km, is due to the fact that one of the electrodes of this line is affected by radical changes in soil-moisture as the seasons change from wet to dry. The eastward line, length 10 km, has its electrodes more advantageously placed in this respect and shows a slow drift like that at Tucson. There is, however, no relationship apparent between these monthly means or their variations and the lengths of lines, or between them and the normal earth-current activity as represented by the diurnal variation. The effects of changes, either seasonal

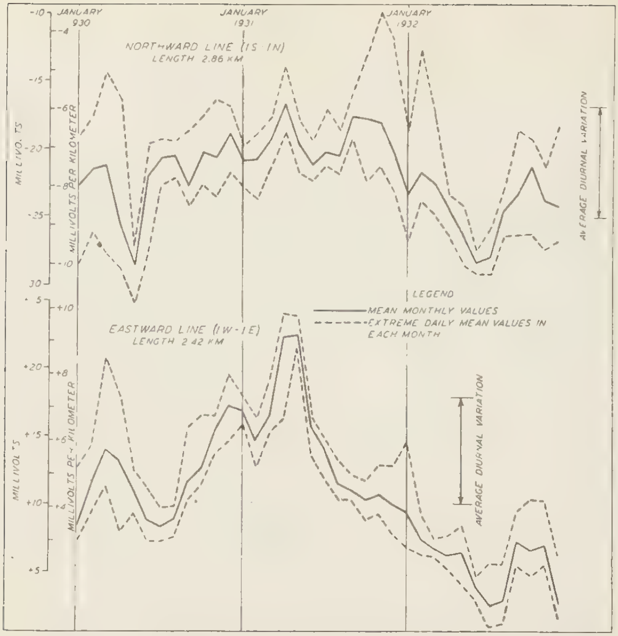

FIG. 2—MONTHLY MEAN VALUES OF POTENTIALS RECORDED ON EARTH-CURRENT LINES AT HUANCAYO, PERU, 1930, 1931, AND 1932, WITH HIGHEST AND LOWEST DAILY MEAN VALUES RECORDED IN EACH MONTH

or random, in the monthly means is also reflected in the daily means and a casual inspection might indicate no consistency in the daily means either. But if the variations in the monthly means are allowed for and consideration is given to the manner in which the extreme daily means depart from the monthly means, the data shown in the three Figures become at once significant. For the departure of the daily means from the monthly means, as shown by the spread of the two dashed curves or by the differences in their ordinates, does exhibit a decided and consistent relationship to the diurnal variation in that it tends in all cases to approximate the magnitude of the diurnal variation.

That such a relationship should hold so consistently despite the great differences in the lengths of the lines, in the magnitudes of the diurnal variations, in the ratios between the mean potentials and the amplitudes of the diurnal variations, and in the performances of the different electrodes as evidenced by the diverse variations in the monthly means, indicates strongly that the variations in the daily means are not accidental but represent variations in earth-current flow. The close agreement between the range of daily means and the amplitudes of diurnal variation offers substantial confirmation to the conclusion, previously reached from a study of the records from the multiple systems at Huancayo and Watheroo, that there exists no constant component in earth-current flow comparable in magnitude to the diurnal variation. It further shows

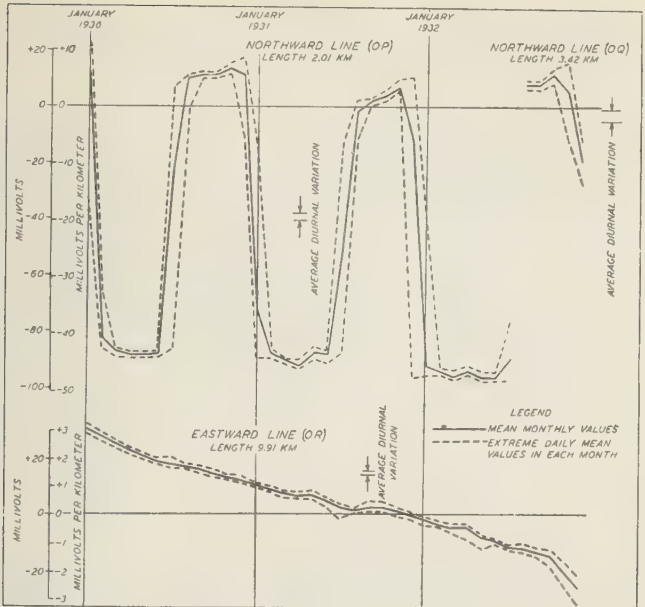

FIG. 3—MONTHLY MEAN VALUES OF POTENTIALS RECORDED ON EARTH-CURRENT LINES AT WATHEROO, WESTERN AUSTRALIA, 1930, 1931, AND 1932, WITH HIGHEST AND LOWEST DAILY MEAN VALUES RECORDED IN EACH MONTH

that any long-period changes which may occur must be small in comparison to the diurnal variation.

As is apparent from Figures 2 and 3, the contact-potentials on the short lines at Huancayo and Watheroo constitute so great a part of the total recorded values that an investigation into variations with periods longer than one day was hardly advisable so long as only these short-line records were available. Once the reduction of the records from the much longer lines at Tucson was under way some systematic differences in the daily means was noted. It was found that the mean potentials recorded on the ten calmest days of each month differed from the mean of the month as a whole in a fairly consistent manner. This is shown in Table 1, in which we find that the average difference between calm-day and all-day means, expressed in terms of potential gradient was 0.07 mv km for the period of four and one-half years covered by the Table, and that the sign of the difference tended to remain the same during the individual months. The sign of the difference was minus in 44 out of 54 months in the records of the northerly component, and in 47 out of 54 months in the case of the eastward component. In only a single instance was the sign of the average yearly difference plus and that only by a small amount.

In view of the consistency shown in Table 1 a comparison of the mean potentials recorded on individual characteristically disturbed and quiet days with those recorded on other days seemed worth while. Comparison with the monthly means is not best suited for this purpose since,

TABLE 1—*Differences between mean potential-gradient recorded on electrically calm days and that recorded on all days on the earth-current lines at Tucson, Arizona*

(Differences shown were obtained by subtracting the mean gradient for all days from that recorded on the ten calmest days of each month)

Year	Northerly component				Eastward component			
	Average difference	Number of months when sign of difference was			Average difference	Number of months when sign of difference was		
		Plus	Zero	Minus		Plus	Zero	Minus
	mv/km				*mv/km*			
1932	+0.01	4	1	7	−0.06	3	0	9
1933	−0.08	1	0	11	−0.09	0	0	12
1934	−0.07	1	1	10	−0.06	1	1	10
1935	−0.12	1	0	11	−0.08	1	0	11
1936 1st half	−0.14	1	0	5	−0.10	1	0	5
Entire period	−0.07	8	2	44	−0.07	6	1	47

in addition to irregular changes, the contact-potentials usually show progressive changes some of which are large as was noted in the Watheroo records at the beginning and end of the rainy season. Hence comparison of individual daily means with those of the month may be greatly affected by the distribution of the individual days throughout the month. To eliminate at least partially the influence of this type of variation in the contact-potentials the individual days were compared with the days adjacent to them.

Table 2 summarizes the results of comparisons made in this way not only for the Tucson records but also for those from Huancayo and Watheroo. The Tucson comparison is based on an electrical classification of days. The five most disturbed and the five calmest days in each month from June 1931 to April 1936 were used and compared with the means of the two adjacent days. Magnetic classification of days was used for Watheroo and Huancayo. The data shown for these stations were for the five international disturbed and quiet days for the years 1930, 1931, and 1932. The relationship between magnetic and earth-current disturbances is so close that it is quite immaterial which classification is used. The electrical classification was used for Tucson merely because it was at hand, having been worked out for other purposes, while the magnetic classification was not available for the entire period.

In the first four lines of Table 2 the differences in daily means between disturbed and adjacent days are shown and the last four lines give similar data for characteristically calm days. Because of the well-known tendency for calm or disturbed periods to extend over a number of days so that high or low character-numbers frequently occur in groups, two sets of differences are shown for each component and for each type of day. Lines 1 and 2 and 5 and 6 show the differences between each disturbed or quiet day and the mean of the day preceding and following it, regard-

ABLE 2—*Differences in mean potential-gradient recorded on earth-current lines at Tucson, Huancayo, and Watheroo on characteristically disturbed and calm days*

Differences shown were obtained by subtracting the mean gradient on the two adjacent days from that recorded on each disturbed or calm day)

eries	Days compared	Cases*	Component	Tucson		Huancayo		Watheroo	
				No. of days	Average difference	No. of days	Average difference	No. of days	Average difference
					mv/km		*mv/km*		*mv/km*
1	Disturbed-adjacent	All	Northward	252	+0.06	150	−0.04	165	−0.02
2	Disturbed-adjacent	All	Eastward	249	+0.07	156	+0.04	153	+0.01
3	Disturbed-adjacent	Isolated	Northward	67	+0.10	37	−0.08	45	−0.09
4	Disturbed-adjacent	Isolated	Eastward	63	+0.07	38	+0.06	44	+0.02
5	Calm-adjacent	All	Northward	267	−0.03	141	+0.01	160	0.00
6	Calm-adjacent	All	Eastward	259	−0.05	151	−0.04	158	0.00
7	Calm-adjacent	Isolated	Northward	69	−0.06	35	+0.03	48	+0.08
8	Calm-adjacent	Isolated	Eastward	60	−0.06	36	−0.07	49	−0.01

*"All cases" include all characteristically disturbed or calm days without reference to the character of the adjacent days, "Isolated cases" include only those instances when neither of the two adjacent days was also a "most disturbed" or "calmest" day, respectively.

less of the character of the adjacent days. The other four lines take in only those instances in which neither of the two adjacent days was also a most disturbed or quietest day, respectively. The data for the isolated cases are unquestionably the better suited for the purposes of the comparison but the number of occurrences are comparatively few when the investigation is restricted to them. So both sets of results are shown for what they may be worth.

It should be pointed out that the data in Table 2 show strictly statistical differences. Individual differences are found to vary widely both in sign and magnitude. On the other hand, if the data are split up into groups as was done with those in Table 1, a similar consistency with time is apparent. Ten six-month groups for Tucson show average differences which in nine cases have the same signs as those shown in the Table. Six half-year groups for Huancayo all have the same sign in lines 1 and 6, while the opposite sign appears once in line 2 and twice in line 5. Groupings of this sort could, of course, only be made in considering all cases. For the isolated cases—lines 3, 4, 7 and 8—the calculated probable error of the differences shown is about one-half the values given in the Table for the results from Tucson and Huancayo. In the case of Watheroo, where the mean potentials recorded and the range of variation in them often are one hundred or more times as great as the diurnal variation, the data are far less consistent. The calculated probable error exceeds the value shown for that Observatory in every case and the results can only be regarded as inclusive, although they do suggest an agreement with the results at the other two stations.

This examination of the daily means at Tucson indicates that the potential gradient tends to be about 0.05 mv km greater on disturbed days and about the same amount less on calm days than it is on an average day. The calm-day difference, it might be noted, is approximately the same as that shown in Table 1. Since the usual convention as to the sign of the gradient has been used it would therefore appear that one feature of earth-current disturbances is a tendency for current to flow

toward the north and east, either as a fairly constant component or one of rather long period. Taking the total differences between a very disturbed day and a markedly calm one, instead of that between each day and an average day, the average potential-gradient due to this current is of the order of magnitude of 0.10 mv/km, which is about two per cent of the range of diurnal variation of the northerly component and six per cent of the diurnal-variation range for the eastward component.

A similar current-component, except that it is directed toward the south and east, is indicated by the Huancayo data, its magnitude being about the same in proportion to the diurnal variation recorded at that station. The Watheroo data, in so far as they have any significance at all, are in agreement with the records from Huancayo as to the direction of the northward current-component, both observatories being situated south of the equator, and to the extent that they indicate a component small in comparison to the diurnal variation.

The general direction of the earth-current flow at Huancayo and Watheroo, as shown in the diurnal-variation records, is decidedly restricted. So also is that at Tucson during most of the year. Without placing too much emphasis on the quantitative results presented here, it might be pointed out that the directions indicated for these disturbance-currents—if we can call them that—fit in with the directions noted in the diurnal-variation records, that is: At Tucson, somewhat west of south to east of north; at Huancayo, west-northwest to east-southeast; and at Watheroo, nearly along the meridian.

It is possible that both the disturbance-currents and the diurnal variations are influenced as to their directions by local geological conditions. For this reason and also because a wider distribution of records would be required to fix with any accuracy the nature of the current-circulation responsible for the gradients indicated in the Tables, speculation on that point must be postponed until further records from these and other stations have been studied.

The main objects of the present paper are (1) to show that a study of long-series earth-current records has possibilities as a method of determining the existence and magnitude of long-period components in earth-current flow, and (2) to demonstrate that any such long-period components which may exist are small in comparison to the usual diurnal variation.

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THE AMERICAN CHARACTER-FIGURE C_A AS A MEASURE OF MAGNETIC ACTIVITY OF THE EARTH[1]

By A. G. McNish and A. K. Ludy

A close relationship between radio-transmission conditions and irregular fluctuations of the Earth's magnetic field has been recognized for some time. The nature of this relationship may be briefly stated as follows: At times when the variations of the Earth's magnetism are of a regular character transmission over long distances is generally good on all frequencies, but when the variations are irregular—that is, during magnetic "storms"—communication over high-latitude paths is unsatisfactory or altogether impossible on the higher frequencies.

In efforts to understand this relationship better, numerous investigators have made correlations of radio conditions and magnetic storminess. Various measures of storminess have been used—sometimes the daily range of magnetic change at a single station, sometimes a subjective estimate of storminess as assigned by the observer-in-charge of a magnetic station. Such measures are not fully adequate as they only partially represent the conditions at a single point on the Earth. Magnetic storms affect the entire Earth although local conditions may vary considerably.

A better measure of storminess is supplied by the international character-figure C. This is the mean of the estimates of storminess assigned for each Greenwich day by about 50 magnetic observatories widely distributed over the Earth. Each observatory assigns the number 0, 1, or 2—0 denoting freedom from storminess and 2 denoting the most intense storminess—to each Greenwich day and communicates the assignments to a central bureau at De Bilt, Netherlands, at the end of

[1]Paper presented at joint meeting of American Section of International Scientific Radio Union and Institute of Radio Engineers, April 30, 1937, Washington, D. C.

each quarter-year. The figures are then compiled and a bulletin issued quarterly. Several faults of this measure of storminess are: (1) The measure is not so representative of world-wide conditions as it might otherwise be since so many of the cooperating observatories are in Europe; (2) the judgments of the various observers are not entirely comparable; and (3) the bulletins are received by investigators quite late.

In accord with a suggestion made at a conference of ionospheric investigators in 1937 at the Department of Terrestrial Magnetism, Carnegie Institution of Washington, steps have been taken to remedy this situation. The Department of Terrestrial Magnetism and United States Coast and Geodetic Survey with the cooperation of the United States Army and United States Navy communication-services and several amateur radio stations have undertaken to supply an American character-figure based upon the reports of the seven American-operated observatories

Table 1—*Magnetic character-figure C_A for Greenwich half-days based on reports from Cheltenham, Honolulu, Huancayo, San Juan, Sitka, Tucson, and Watheroo*

Day	March, 1937		April, 1937		May, 1937	
	0^h-12^h	12^h-24^h	0^h-12^h	12^h-24^h	0^h-12^h	12^h-24^h
1	...	...	0.2	0.2	0.7	0.4
2	...	...	0.6	0.6	0.1	0.1
3	...	...	0.9	0.8	0.1	0.4
4	...	...	0.2	0.2	0.4	1.1
5	...	...	0.0	0.0	1.8	1.1
6	...	...	0.1	0.2	0.1	0.0
7	...	...	0.1	0.4	0.1	0.1
8	...	...	0.1	0.0	0.0	0.1
9	...	...	0.0	0.1	0.4	0.6
10	...	...	0.0	0.1	0.5	0.4
11	...	...	0.4	0.1	0.6	0.1
12	...	...	0.2	1.0	0.1	0.1
13	0.2	0.8	0.4	0.1	0.2	0.3
14	1.0	0.3	0.0	0.1	0.3	0.5
15	0.8	1.1	0.0	0.4	0.4	0.1
16	0.3	0.2	0.1	0.1	0.5	0.4
17	0.4	0.3	0.1	0.4	0.1	0.1
18	0.1	0.1	0.4	0.4	0.0	0.1
19	0.0	0.0	0.3	0.6	0.5	0.1
20	0.0	0.1	0.3	0.1	0.0	0.1
21	0.0	0.4	0.5	0.1	0.0	0.4
22	0.8	1.2	0.0	0.1	0.1	0.3
23	0.6	0.4	0.0	0.1	0.3	0.1
24	0.1	0.5	0.2	1.6	0.1	0.3
25	0.3	0.1	1.3	1.9	0.4	0.4
26	0.1	0.7	1.3	1.8	0.6	0.4
27	1.0	1.1	1.5	1.4	0.3	0.9
28	0.7	0.3	1.9	1.9	1.0	0.9
29	0.1	0.2	0.6	0.7	0.9	0.3
30	0.2	0.6	0.6	0.7	0.4	0.2
31	1.7	0.9			0.2	0.0
Means	...	...	0.4	0.5	0.4	0.3
	..		0.5		0.3	

—those of the Department of Terrestrial Magnetism at Huancayo in Peru and at Watheroo in Western Australia, and those of the United States Coast and Geodetic Survey at Cheltenham (Maryland), Honolulu (Hawaii), San Juan (Puerto Rico), Sitka (Alaska), and Tucson (Arizona). This character-figure is being designated C_A. The locations of these observatories are shown in Figure 1.

Each observatory assigns the figure 0.0, 0.5, 1.0, 1.5, or 2.0—0.0 denoting freedom from storminess and 2.0 denoting the most intense storminess—to each half-day running from 0^h to 12^h and from 12^h to 24^h GMT. These assignments are transmitted to Washington by radio at weekly intervals where a bulletin is compiled by the Department of Terrestrial Magnetism, Carnegie Institution of Washington, giving the average ratings for all the stations for each half-day. A bulletin is prepared each Tuesday, giving the data for the week ending at midnight GMT the preceding Friday, and sent to Science Service to be included in the weekly bulletin of cosmic data distributed by that Service.

This measure was inaugurated March 23, 1937, supplying data for the week ending March 19. The values of C_A from March 13 through May 1937 are given in Table 1. A comparison of the character-figures assigned for each entire Greenwich day by the seven American-operated observatories and the international character-figures is shown in Figure 2.

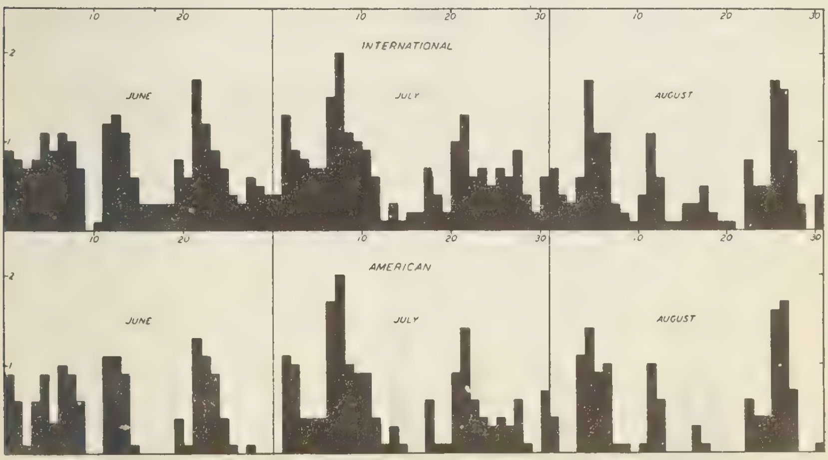

FIG. 2—COMPARISON INTERNATIONAL AND AMERICAN MAGNETIC CHARACTER-FIGURES, JUNE TO AUGUST, 1928

Although the American character-figure averages are lower than the international character-figure the variations are in close agreement. The tendency of magnetic storms to recur at 27-day intervals may be noted in Figure 2.

The significance of this American character-figure as an index of radio-transmission conditions is brought out in Figure 3[2] in which the precentage

[2]The writers are indebted to L. V. Berkner of the Department of Terrestrial Magnetism, Carnegie Institution of Washington, for the data on radio transmission extracted from a paper by I. S. Bemis (Proc. IRE, **19**, pp. 1931-1947, 1931) in which radio reception was correlated with magnetic storms. Berkner called attention to a closer relationship when the international character-figure was used.

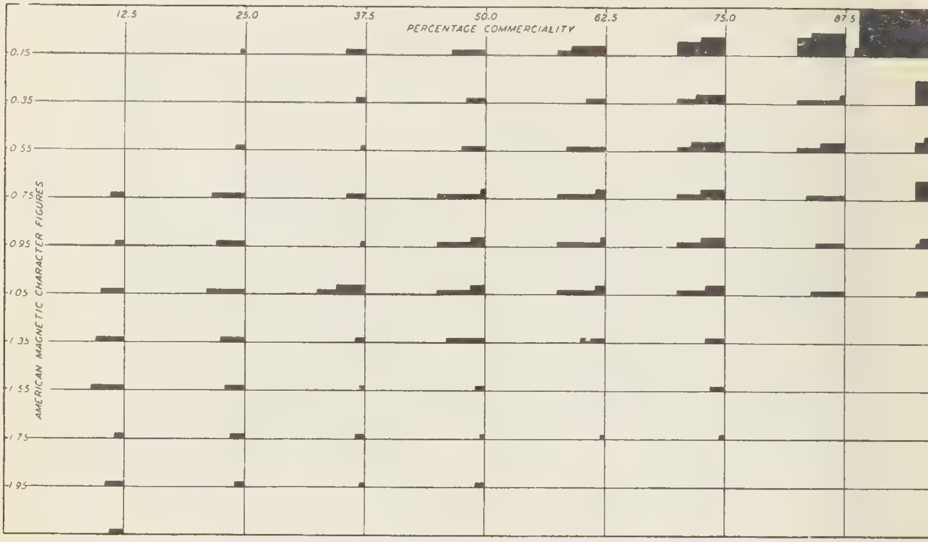

FIG. 3—RELATION MAGNETIC STORMINESS AND QUALITY TRANSATLANTIC RADIO RECEPTION ON INDIVIDUAL DAYS, MAY 28, 1928 TO DECEMBER 31, 1930

of time North Atlantic radio circuits were satisfactory for commercial use on each day is coordinated with the American character-figure for that day during the period May 28, 1928 to December 31, 1930. It is obvious that the new service should prove of considerable value in forecasting radio-transmission conditions many days, or possibly months, in advance

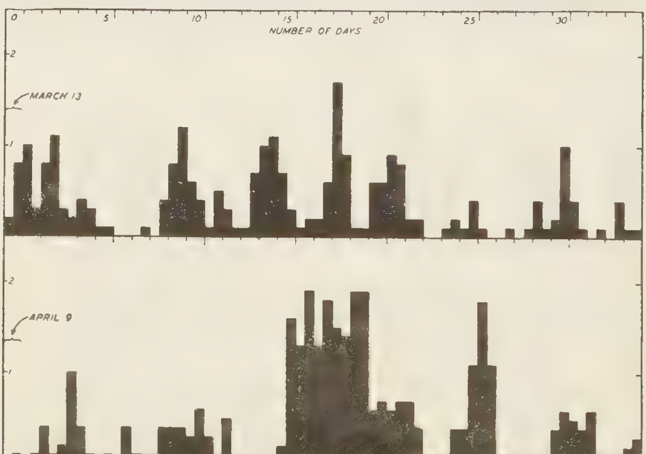

FIG. 4—AMERICAN MAGNETIC CHARACTER-FIGURES FOR GREENWICH HALF-DAYS, MARCH 13 TO MAY 13, 1937

because of the tendency of magnetic storms to recur at 27-day intervals. Figure 4 shows the American character-figure for the half-days from time of its inception through the most recent report, ordered in the 27-day sequence. Twenty-seven days after a low character-figure good radio transmission may be expected and the same time after a high character-figure the converse may be expected.

Recognition must be given the observers at the several stations upon whose careful, accurate, and punctual reports this service depends. Also, the communication-service of the United States Army and United States Navy and the several radio amateurs concerned are to be congratulated on the efficient manner in which the transmission of this intelligence has been handled. The time and effort expended on their part is considerable, but the value of this service to society promises to completely justify the undertaking.

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NOTES

(See also page 108)

13. *Intercomparisons in Pacific Region*—W. C. Parkinson of the Department of Terrestrial Magnetism, Carnegie Institution of Washington, obtained, during the course of his recent field-work in Australasia, comparisons of the standards at the Watheroo Magnetic Observatory (Western Australia) and at the Christchurch Magnetic Observatory (Amberley, New Zealand). He also intercompared his instruments with the instruments being used in the magnetic-survey work in Southern Australia under the auspices of Government Astronomer G. F. Dodwell at Adelaide, as well as with those loaned by the Carnegie Institution of Washington and now being used in the Geophysical Survey of Northern Australia. He expects during June 1937 to intercompare his instruments with the standard instruments of the Apia Observatory (Western Samoa) under the direction of J. Wadsworth. Following these intercomparisons it is planned that he will obtain the relation between the international magnetic standard of the Carnegie Institution of Washington, carried by his instrument, and the standards of the United States Coast and Geodetic Survey at its Honolulu Magnetic Observatory. CIW magnetometer No. 13 which is being shipped for field-work in China has been forwarded to Honolulu and will be intercompared also with the standards there by Mr. Parkinson and Lieutenant Commander J. H. Peters, Observer-in-Charge of the Honolulu Magnetic observatory. Later, upon arrival in China, it is hoped that magnetometer-inductor No. 13 may be compared with the standard instruments of the several Chinese observatories. Father M. Burgaud, in charge of the magnetic work of the Zi-ka-wei and Zosè observatories and Dr. S. L. Ting, Director, National Research Institute of Physics, Academia Sinica, will extend the cordial cooperation which they have so far tendered the efforts of the Department of Terrestrial Magnetism, Carnegie Institution of Washington, in the prosecution of the world survey. The results of this campaign of intercomparisons will afford further excellent control of observatory-standards.

14. *Personalia*—Dr. *Thomas C. Poulter*, Director of the Armour Institute of Technology, Chicago, Illinois, second in command of the Byrd Antarctic Expedition of 1933-35, was presented April 27, 1937, with a special medal by the National Geographic Society, Washington, D. C. On the Byrd Expedition Dr. Poulter's work included geophysical investigations, studies of ice-conditions, terrestrial magnetism, and observation of meteors and auroral phenomena.

On April 16, 1937, there was held at the Arctic Institute, Leningrad, a celebration of the 25th anniversary of Professor *W. Wiese's* activity in polar research.

A commemorative academy is now scheduled for October 23 or 24, 1937, at Warsaw, Poland, in honor of Professor *Stanislas Kalinowski*, founder of the Swider Magnetic Observatory, in celebration of the fortieth anniversary of his scientific activity. It was originally planned to hold this function May 9, 1937, but for reasons of a technical nature, it has been postponed to the later date.

It was announced in the list of Coronation Honors that Dr. *J. M. Stagg*, Senior Technical Officer in the Meteorological Office, had been made an Officer of the Order of the British Empire.

Dr. *J. A. Fleming*, Director of the Department of Terrestrial Magnetism, of the Carnegie Institution of Washington, has been elected as one of the members of the Executive Committee of the International Council of Scientific Unions.

Dr. *Harlan T. Stetson* has been appointed Research Associate on Cosmic Terrestrial Relationships, at the Massachusetts Institute of Technology, Cambridge, Massachusetts.

Dr. *F. J. W. Whipple*, Superintendent of Kew Observatory, has been elected President of the Royal Meteorological Society of London.

W. Ralph Dyer was acting director of the Apia Observatory, Apia, Western Samoa, from August 20, 1936, to April 16, 1937, during the absence of Director *J. Wadsworth* who was at the Meteorological Office in Wellington, New Zealand.

Prof. Dr. *Heinrich Meldau*, known for his studies of the magnetic compass, died at Bremen, April 23, 1937, at the age of 71 years.

ON THE LUNAR-DIURNAL VARIATION IN THE EARTH-CURRENTS

By J. Egedal

In examining earth-potentials at Jersey Marc Dechevrens[1] twenty years ago found variations of tidal type, and in examining ordinary earth-current observations the author[2] demonstrated a lunar influence on the earth-current potential-gradient at Ebro, Spain, for the hours 10 to 11 a.m. In the following a complete determination of the lunar-diurnal variation of the earth-current potential-gradient will be mentioned and discussed.

The observational data The data used for the present determination of the lunar-diurnal variation of the earth-current potential-gradient are taken from the earth-current observations made at Ebro in the period January 1 to December 21, 1910 (12 lunations). Only the data designated N→S, giving the potential-gradient in a direction 25° west of north, have been examined.

The question whether earth-current data, commonly being much affected by electrode-potentials, were sufficient for the determination of a small variation like the lunar-diurnal variation could not be answered beforehand, but as W. J. Rooney[3] has found, large electrode-effects may be present without disturbing the solar-diurnal variation seriously.

The disagreement between the theoretically determined amplitude of the solar-diurnal variation of the earth-currents derived by S. Chapman and T. T. Whitehead[4] for Ebro and the observed one has by O. H. Gish[5] been considered as due to the large electrical resistance of the earth at that place. The disagreement therefore possibly does not reveal errors in the earth-current measurements at Ebro.

Although the lunar-diurnal variation may be affected in other ways than the solar-diurnal variation yet a determination of the former does not beforehand seem impossible. The large electrical resistance of the earth at Ebro in certain respects makes the place fit for the determination of earth-current variations with small amplitudes.

The determination and result--The methods used for the determination of the lunar-diurnal variation and of lunar variations for certain hours of the day are the same as those mentioned in a paper by M. Bossolasco and the author[6].

In Table 1 the main term of the variation (L_2) is given for each lunation.

[1]Terr. Mag., **23**, 37-39 and 145-147 (1918).
[2]J. Egedal, Zs. Geophysik, **6**, 157-158 (1930).
[3]W. J. Rooney, Terr. Mag., **37**, 363-374 (1932).
[4]Terr. Mag., **28**, 125-128 (1923).
[5]O. H. Gish, Sci. Mon., **32**, 5-21 (1931).
[6]Terr. Mag., **42**, 123-126 (1937).

Table 1—*Lunar-diurnal variation of the earth-current potential-gradient at Ebro, 1910 (direction, 25° west of north)*

Lunation	Main term L_2 in mv/km	Lunation	Main term L_2 in mv/km
Jan 1 to Jan 31	1.3 sin $(2t+18°)$	Jun 28 to Jul 28	2.8 sin $(2t+70°)$
Jan 31 to Mar 2	2.2 sin $(2t+36°)$	Jul 28 to Aug 26	3.8 sin $(2t+28°)$
Mar 2 to Apr 1	2.4 sin $(2t+ 0°)$	Aug 26 to Sep 24	3.3 sin $(2t+37°)$
Apr 1 to Apr 30	2.5 sin $(2t+ 7°)$	Sep 24 to Oct 23	1.5 sin $(2t+ 4°)$
Apr 30 to May 30	2.1 sin $(2t+58°)$	Oct 23 to Nov 22	1.3 sin $(2t+23°)$
May 30 to Jun 28	0.8 sin $(2t+28°)$	Nov 22 to Dec 21	1.7 sin $(2t+73°)$

The lunar-diurnal variation for the whole period (12 lunations) is shown in Figure 1. The following value for L_2 is found

$$L_2 = 1.95 \sin (2t + 33^\circ) \text{ mv/km}$$

and the amplitude and its standard deviation are 1.95 ± 0.13 mv/km.

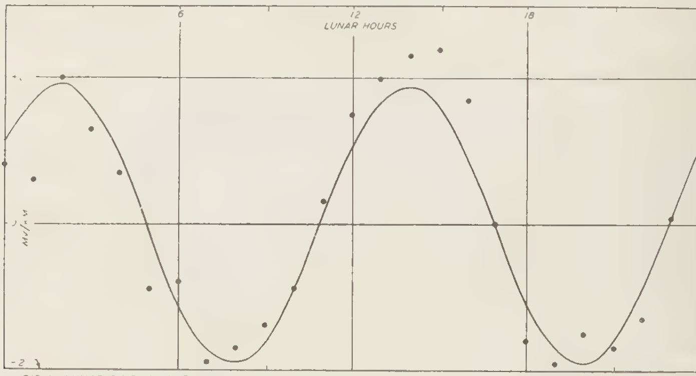


FIG. 1—LUNAR DIURNAL-VARIATION OF EARTH-CURRENT POTENTIAL-GRADIENT, EBRO OBSERVATORY, 1910

Discussion—The amplitude of the lunar-diurnal variation found with good accuracy is one-tenth of the range of the solar-diurnal variation for the currents in the direction considered here. For the variations of the magnetic declination of stations lying in the same latitude as Ebro the corresponding proportion is only one-thirtieth. Thus the amplitude of the lunar-diurnal variation of the potential gradient seems to be greater than might be expected.

In order to examine this question more closely, the lunar variation for certain hours of the night might be determined. During the night the solar-diurnal variations are small, and therefore the lunar-diurnal variation also might be expected to be small, and, consequently, it might be possible to discover an erroneous lunar variation, if such a variation took place independently of the daily variation.

In Table 2 the main term L_2 of the lunar variations for pairs of the night-hours during the year 1910 are given.

Table 2—*Lunar variations of earth-current potential-gradient during solar hours 20 to 5 at Ebro Observatory for the year 1910*

Hour	Main term L_2 in mv/km
20 to 21	$2.4 \sin (2t+146^\circ)$
22 to 23	$2.4 \sin (2t+162^\circ)$
0 to 1	$2.0 \sin (2t+141^\circ)$
2 to 3	$1.3 \sin (2t+187^\circ)$
4 to 5	$1.4 \sin (2t+138^\circ)$

The value of L_2 for the hours 20 to 5 is found to be

$$L_2 = 1.8 \sin (2t + 154^\circ) \text{ mv/km}$$

and the amplitude and its standard deviation are 1.8 ± 0.23 mv km. For the day-hours 6 to 19 the following value of L_2 is found

$$L_2 = 4.1 \sin (2t + 18°) \text{ mv/km}$$

It will be seen that the amplitude for the night-hours also is found with good accuracy, that it is nearly equal to the mean amplitude, and further that the phase-angle for the night-hours differs about 120° from the phase-angle for the mean variation.

It is evident that the lunar variation for the night-hours is not of the same origin as solar and lunar magnetic variations, but now the question is whether its origin is geophysical[7] or observational. Probably the variation originates from the electrode-potentials, which may be affected at the electrodes by tidal variation of the pressure in the Earth.

Until this question is solved it will not be possible to make full use of the results from determinations of the lunar-diurnal variation of the earth-current potential-gradient.

The phase-angles found in this analysis, especially those for the day-hours, seem to indicate that the lunar-diurnal variation varies proportionally with the rate of the changes in the lunar-diurnal variation of the magnetic declination, but future investigations are to confirm this point definitely.

Summarizing, it may be said that the existence of a lunar-diurnal variation in the earth-current potential-gradient is confirmed, and that in order to advance the study of this variation a closer examination of the observations and a comparison of results from different places are necessary.

[7]It should be remembered that for coastal regions irregular variations of the earth-currents have been observed (see E. Mathias: Traité d'électricité atmosphérique et tellurique, 468-469, Paris 1924).

Copenhagen, Denmark

REVIEWS AND ABSTRACTS

D. Brunt: *Climatic cycles*, Geog. J., **89**, 214-238, March 1937.

Discussing cycles in meteorological phenomena the author expresses strong doubt that any of the purported cycles except those based on known astronomical phenomena follow a regular system of recurrence. Although the existence of trends in weather-conditions is readily admitted Dr. Brunt does not consider that they represent consistent fluctuations to which the term cycle may be applied.

Even if several of the cycles which have been claimed do exist in meteorological elements they have no value for prognostication. Dr. Brunt points out that statistical examination of the variations in rainfall, etc., shows that the variability is so great that that portion of the variability contributed by the so-called cycle is negligible.

A random drawing of numbers and arrangement of them in the order in which they are drawn is likely to produce an array in which cycles appear. A test for the reality of a cycle must show that the amplitude of the cycle discovered must be considerably greater than the amplitude which one would expect from a similar array of random numbers.

Dr. Brunt does not point out that a number of cycles have been claimed which when submitted to statistical tests outlined by him appear to be real. The apparent reality of these cycles, in the opinion of this reviewer, arises through the coarseness of the test proposed by Dr. Brunt. His test takes no account of the correlative nature of meteorological variables which requires that a more stringent criterion be used in testing for reality of cycles. (See A. G. McNish, Trans. Amer. Geophys. Union, seventeenth annual meeting, 124-129, 1936).

The discussion which followed Dr. Brunt's paper is very illuminating. Those who argued for the existence of cycles produced no evidence to support their reality such as suggested by Dr. Brunt. The remark by Sir Gilbert Walker is particularly pertinent: "I do not know of a single period, other than those of sunspots, of which the reality is clearly established by the necessary use of mathematical criteria; and some of the period-finders seem to recognize this, for at least one has said that he has ceased to pay attention to criteria because when he did so he obtained scarcely any results of interest."

A. G. McNish

M. Hasegawa: *On the type of the diurnal variations of the terrestrial magnetism on quiet days, A statistical study of the type of diurnal variations of terrestrial magnetism on quiet days, Representation of the field of diurnal variations of terrestrial magnetism by the method of graphical integration, On the progressive change of the field of diurnal variations of terrestrial magnetism.* Tokyo, Proc. Imp. Acad., v. 12, 88-90, 185-188, 221-224, 225-228, and 277-280 (1936).

This interesting series of papers treats the variability of diurnal variations in terrestrial magnetism from day to day. In the first paper differences in type of diurnal variations observed at the Aso Magnetic Observatory, latitude 32° 52′ north, longitude 131° 03′ east, are noted. The conspicuous feature of these differences is a change from a mid-day minimum to a mid-day maximum in the X-component of intensity. By a comparison with records from other observatories located near the same meridian the distribution of this diurnal variation is mapped out for two days on which the difference in type was conspicuous. It is found that the transition from mid-day maximum, characteristic of equatorial regions, to mid-day minimum, characteristic of high latitudes occurs some 15° further north on some days than on others.

Employing data from observatories distributed over the Earth, representations of the current-systems necessary to produce the diurnal variations on the individual days are obtained by spherical harmonic analysis. A similar study is made using the method of graphical integration as applied by Chapman to determine the potential distribution. The differences in the potential-function or the current-system on the individual days are striking. They resemble the average idealized current-system for the entire Earth only in a general way.

In the last paper the progress of the centers of the current-system around the Earth on the individual days is studied by locating the transition-region from the data of various observatories. The progress is halting and the path is not confined to a narrow latitude belt for all days. At times subsidiary centers seem to be developed near the main centers. No decision is reached whether the paths of the centers depend upon certain regular features of the Earth or only on adventitious conditions. It seems, in view of certain investigations made at the Department of Terrestrial Magnetism of the Carnegie Institution, that certain general characteristics of the paths are determined by the configuration of the general magnetic field of the Earth, particularly a southern displacement of the paths around the meridian 285° east.

The importance of these studies to theories of terrestrial-magnetic variations should be pointed out. Although no theoretical conclusions were given in the papers, such instability of the current-system strongly supports the Stewart-Schuster theory of the diurnal variations and is in contradiction to the expectations of the drift-current and diamagnetic theories. In order to account for the effects brought out in these papers on the basis of the drift-current or diamagnetic theories very irregular local ionization of the upper atmosphere would be required, while on the basis of the Stewart-Schuster theory they could be explained by local winds for which other evidence exists.

Terrestrial-magnetic studies, when comprehensive, have usually dealt with average data—thus concealing many important facts such as are brought out in this series of papers. It is to be hoped that the investigations may be continued for they promise results of great value to our understanding of terrestrial-magnetic phenomena.

A. G. McNish

STUDY OF RADIO FADE-OUTS

By L. V. Berkner and H. W. Wells

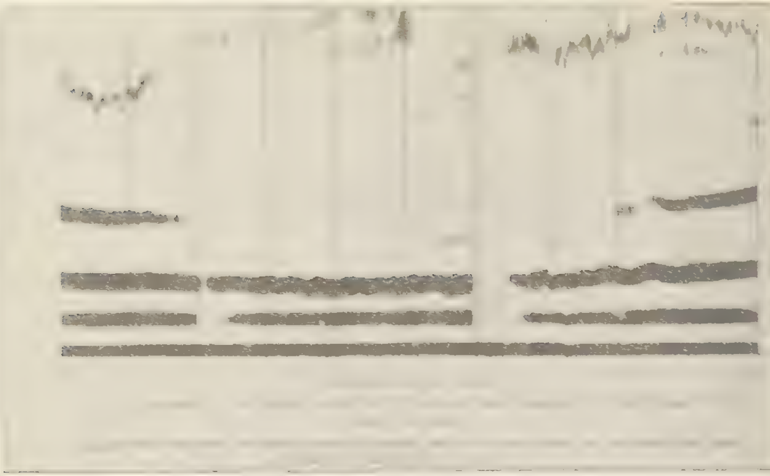
Abstract—The radio fade-out effect reported by Dellinger and Jouaust can be studied from the echo-disappearance observed on the ionospheric traces during such disturbances. Twenty months of continuous data from Huancayo (Peru) and five months of data from Watheroo (Western Australia) are analyzed. The data are presented in more quantitative form than heretofore available. The results are in general agreement with the reports of Dellinger except that no recurrence or quasi-recurrence tendency can be shown from the data available. It is concluded that the data support Dellinger's hypothesis of the origin of these effects in bright chromospheric eruptions and that the effect is an absorption of high-frequency radio waves in the region between about 60 and 100 km because of increase of ionization. The higher ionospheric regions are apparently unaffected, indicating no appreciable absorption of the radiation causing the fade-out, in these regions.

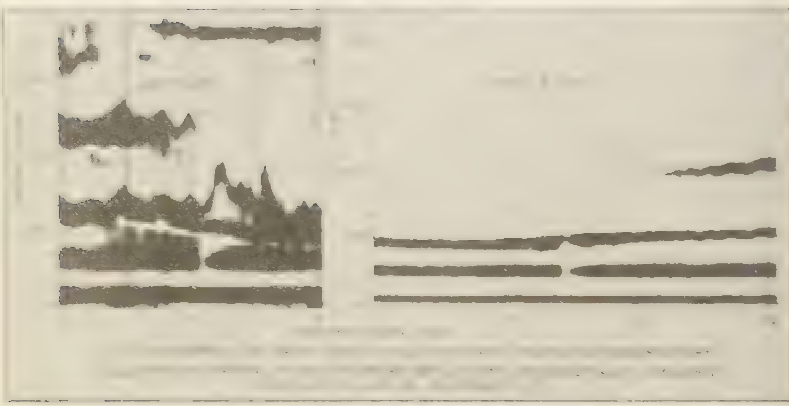
Continuous records of ionospheric heights obtained on a fixed frequency offer certain advantages in the study of radio fade-out effects recently reported by Dellinger[1] [1 of "references" at end of paper] and by Jouaust [2]. While the radio fade-out is ordinarily observed as a diminution or disappearance of a high-frequency radio signal in point-to-point communication, certain details of the nature of this echo-disappearance can be ascertained only from records made at vertical incidence which show the heights of reflection just before and just after the effect [3]. The continuous records of ionospheric heights made at the Huancayo Magnetic Observatory (Peru) and the Watheroo Magnetic Observatory (Western Australia) of the Department of Terrestrial Magnetism, Carnegie Institution of Washington, therefore lend themselves to an analysis of the fade-out effect. The records upon which this study is based are practically continuous from July 1, 1935, at Huancayo and from October 1, 1936, at Watheroo. Records of virtual height are obtained on a frequency of 4.8 mc sec. The data here reported extend for the most part through February 1937—20 months at Huancayo and five months at Watheroo.

During the period under observation, 148 distinct fade-out effects were observed at Huancayo and 43 at Watheroo. It is desirable to distinguish the relative intensity and duration of each fade-out so that their importance to such closely related phenomena [1, 4] as sunspot-activity, magnetic effects, and earth-currents can be assessed and their intensities at different stations compared. We have therefore arbitrarily subdivided these fade-outs into four classifications, easily recognizable on the records, as follows: The more pronounced, intensity 3; those of moderate intensity, intensity 2; those of slight intensity, intensity 1; a slight diminution of echo-strength, just recognizable on the record but nevertheless noticeable in wave propagation over long distances, intensity 1/2.

Numerous examples of fade-outs of each relative intensity have been observed; typical records showing fade-outs of various intensities are reproduced in Figures 1-5. The most intense effect is illustrated in Figure 1, which shows two fade-outs of intensity 3 during an afternoon. It will be observed that at the commencement of the effect, reflections from both the E- and F_1-regions[1] disappear [5]. Figure 2 illustrates a a less severe effect, denoted as intensity 2, in which the intensity of the main (F_1-region) reflection is diminished, accompanied by a corresponding weakening or disappearance of the E-region reflection. Effects of

[1] It will be noted that reflections from both E- and F_1-regions are present in all records from Huancayo on a frequency of 4.8 mc/sec. This is above the E critical-frequency. The reflection from the E-region (110 km) on this frequency is less than one-tenth as strong as the reflection from the F_1-region (200 km) and apparently occurs because of a partial reflection from the relatively high ion-gradient at the lower boundary of the E-region.





intensity 1, illustrated in Figure 3, are evidenced by an appreciable weakening or disappearance of echoes from the E-region, or in the multiple reflections from the F_1-region, but no reduction in the main reflection which is detectable on the record. Effects of intensity 1/2 are extremely small being detectable only as a very slight diminution in the E-region reflection, or in the second or third multiples of the main reflection. Effects of this type are doubtless frequently overlooked or unrecognized in the examination of the records.

In most cases the intensity can be determined from casual examination of the records, but occasionally the effect is greatly variable. Such an occasion is illustrated in Figure 4 where fade-outs of varying intensity occurred in quick succession through an interval of a few hours.

The records yield immediately two facts of importance in determination of the region in which absorption of the radio wave during fade-out

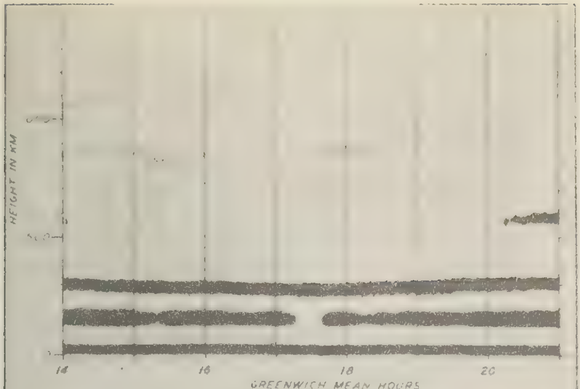


FIG. 3—EXAMPLE OF RADIO FADE-OUTS, HUANCAYO MAGNETIC OBSERVATORY, MARCH 21, 1936
[EFFECT OBSERVED IN E-REGION ONLY WITHOUT APPRECIABLE DIMINUTION OF F-REGION ECHOES SUGGESTING CHANGE IN BOUNDARY-CONDITIONS—NOTED AS INTENSITY 1]

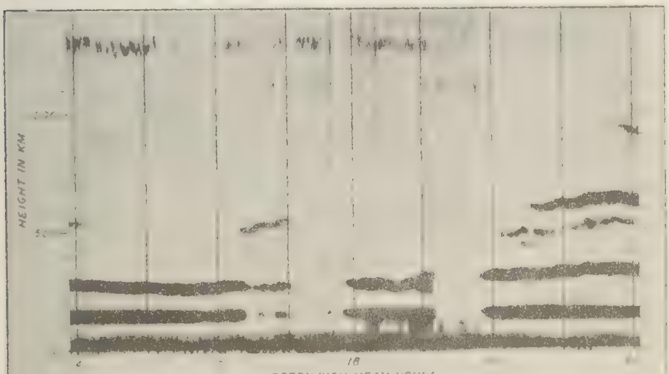


FIG. 4—EXAMPLE OF RADIO FADE-OUTS, HUANCAYO MAGNETIC OBSERVATORY, NOVEMBER 24, 1936
[ILLUSTRATION REPEATED EFFECTS OF VARYING INTENSITY]

occurs. In all records, the effect is evident first in reflections from the *E*-region. This points to a destruction of the normal gradient of ionization at the lower *E*-region boundary at the commencement of the fade-out. At the end of the fade-out, reflections are observed from the same height and are of the same general character as before the fade-out occurred. No appreciable change in height from the normal trend is noted even in the high-order multiples where such an effect would be greatly magnified. These facts indicate that the fade-out does not affect the ionospheric regions above about 110 km but that an absorbing region below the ordinary reflecting regions must appear. This absorbing region extends upward to the lower part of the *E*-region, whose normal

lower boundary is destroyed. These facts place the upper limit of this absorbing region at about 100 km.

The simultaneity of radio fade-outs with bright chromospheric eruptions in the region of sunspots has been shown by Dellinger [1], who suggests that this highly absorbing region is created by intense ionization produced by radiation emanating from the flare. If the absorbing level exists below the *E*-region, as is indicated, the radiation creating it must have passed through the upper regions. Therefore a careful examination of both fixed- and variable-frequency records for change of maximum ion-density has been made. With one exception, no appreciable change in maximum ion-density of the regions above the absorbing region has been noticed. This exception is shown in Figure 5, where the ion-density

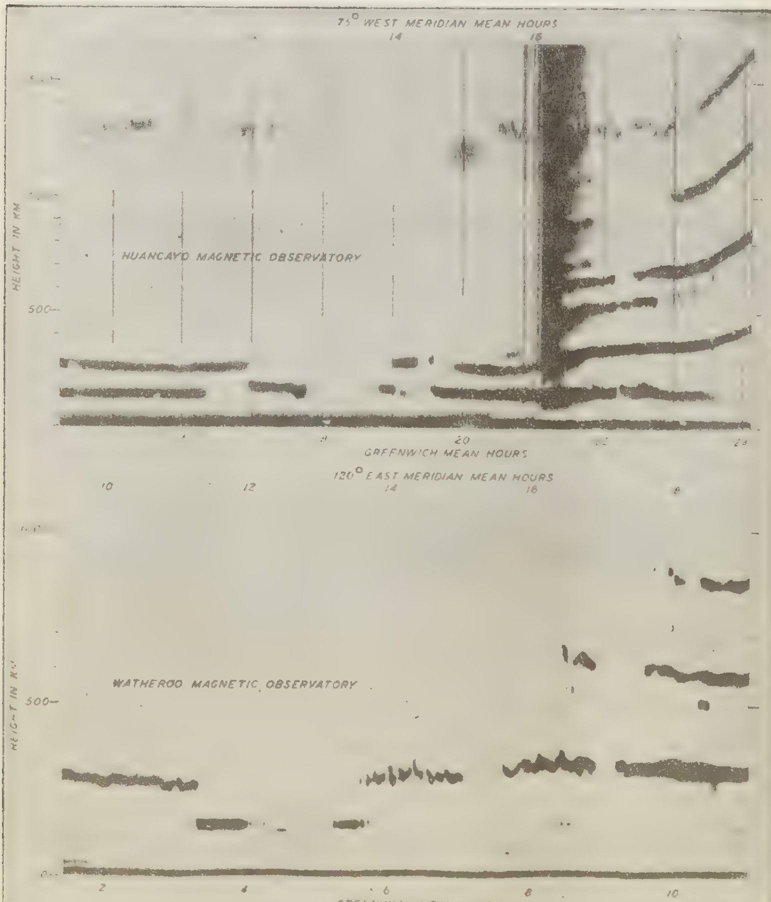


FIG. 5—EXAMPLE OF RADIO FADE-OUTS, NOVEMBER 26, 1936 [SUCCESSION OF RADIO FADE-OUTS WITH TIME FOLLOWING SUNLIT HEMISPHERE]

of the E-region must have increased by more than 50 per cent above normal prior to the fade-out. It is probable that in this case, the fade-out was coincident with an abnormal or "sporadic" ionization of the E-region —in fact the frequency of both effects is such that a few such coincidences are to be expected. As a consequence of these observations, it appears that the ionizing radiation producing fade-outs must pass through the upper regions without materially affecting them. The absorption in these upper regions may be highly selective, and the major emission in the solar flares of such wave-length range as is negligibly absorbed in the E- and F_1-regions. A critical examination of the absorption-spectra of gases known to exist in the upper atmosphere should lead to important conclusions concerninging its physical constitution.

Table 1 gives the data relating to all fade-outs observed at Huancayo from July 1, 1935, to February 28, 1937, and at Watheroo from October 1, 1936, to February 28, 1937. Under the column "Remarks" are entered the times of beginning of fade-outs as reported by Dellinger [1] which closely correspond in time to effects observed at Huancayo and Watheroo.

These data are plotted in Figure 6 which gives the dates and intensities

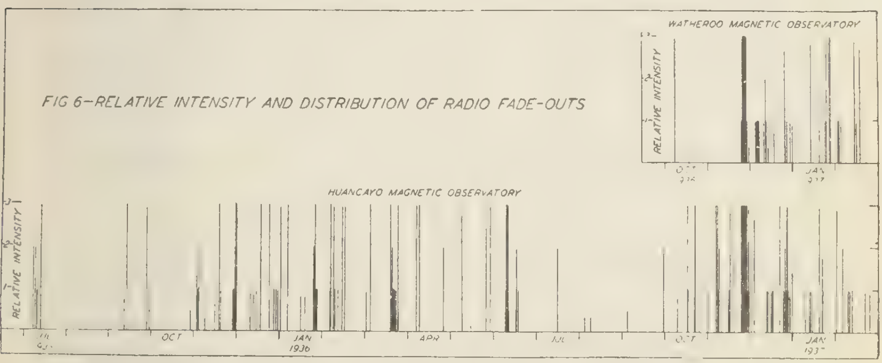


FIG 6—RELATIVE INTENSITY AND DISTRIBUTION OF RADIO FADE-OUTS

of the fade-outs. It is immediately noticed that the frequency of occurrence of these fade-outs has increased during the period of observations—during 1935 and early 1936 they are much less numerous than during the latter part of the period covered. This suggests a relation to sunspot-activity which has risen during this time a relation which should follow if the source of these effects is in the bright chromospheric eruptions in the region of sunspots. Accordingly a correlation has been made between the monthly numbers of fade-outs and sunspots for the few months of observation available. This correlation is represented in Figure 7. The resulting correlation-coefficient is $+0.53 \pm 0.10$. This is as close as might be expected when it is remembered that not all sunspots are sources of chromospheric eruptions but that, in general, the eruptions occur more frequently when sunspots are more numerous.

Further examination of Figure 6 discloses that fade-outs tend to come in groups, that is, when one occurs there is a tendency for a whole sequence to appear. Such a succession of fade-outs is shown in Figure 5. The first was observed at Watheroo at about 4^h GMT followed by a

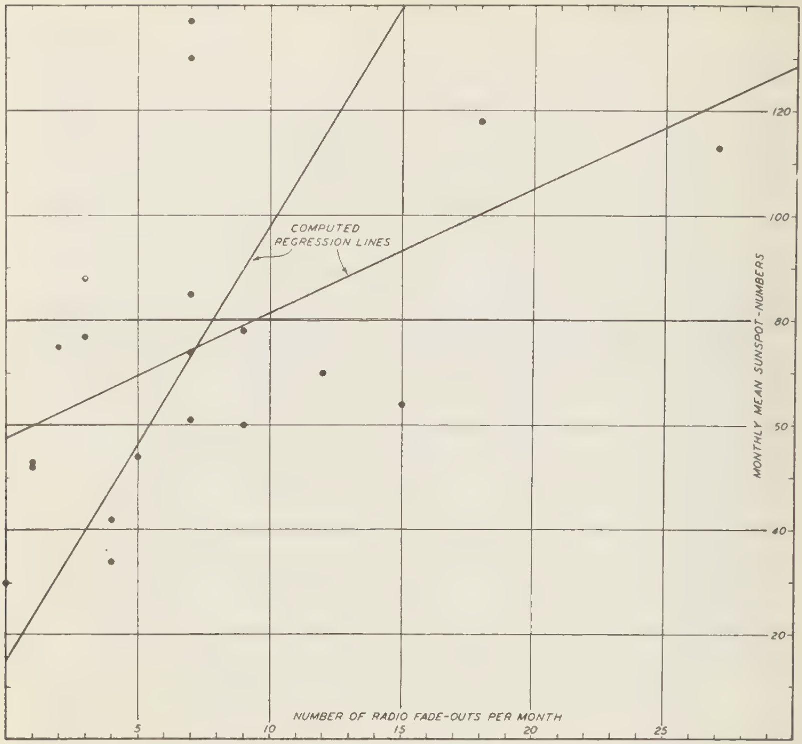


FIG. 7—CORRELATION OF RADIO FADE-OUTS AT HUANCAYO MAGNETIC OBSERVATORY WITH SUNSPOT-NUMBERS

number of fade-outs during the daylight hours. Following sunrise at Huancayo, in the opposite hemisphere, they continue there; such series of fade-outs, following around the Earth in the sunlit hemisphere seem to occur frequently. It must be mentioned that the fade-outs shown in Figure 5 occurred at very nearly the same local times at both stations. However, this is the only such case of correspondence in local time which has been observed at the two stations and the implications must be dismissed for the present, in the absence of confirming data, as accidental coincidence.

Inspection of Figure 6 shows an apparent concentration of fade-outs during the months between October and April. This happens to be the period during which the highest values of F_2-critical frequency are also observed [6]. Whether or not any relation exists between the fundamental phenomena behind these effects cannot be determined from the meager data avalable.

The data of Figure 6 have been examined for recurrence-tendencies such as have been suggested [1, 2]. It can only be concluded that the data are not sufficiently long to determine any real effect. Almost any quasi-recurrent period may be found but none will withstand the mathematical tests for reality.

It will be seen from Table 1 that fade-outs occur at a station only during the sunlit hours as has been previously pointed out by Dellinger [1]. This is illustrated in Figure 8 where the total number of minutes of fade-out in each hourly interval during the entire period of observation is plotted. One should not attach too much importance to the tendency of the effect to be shifted to the afternoon hours because of the limited sample available. It can be seen from Figure 8, however, that the effect

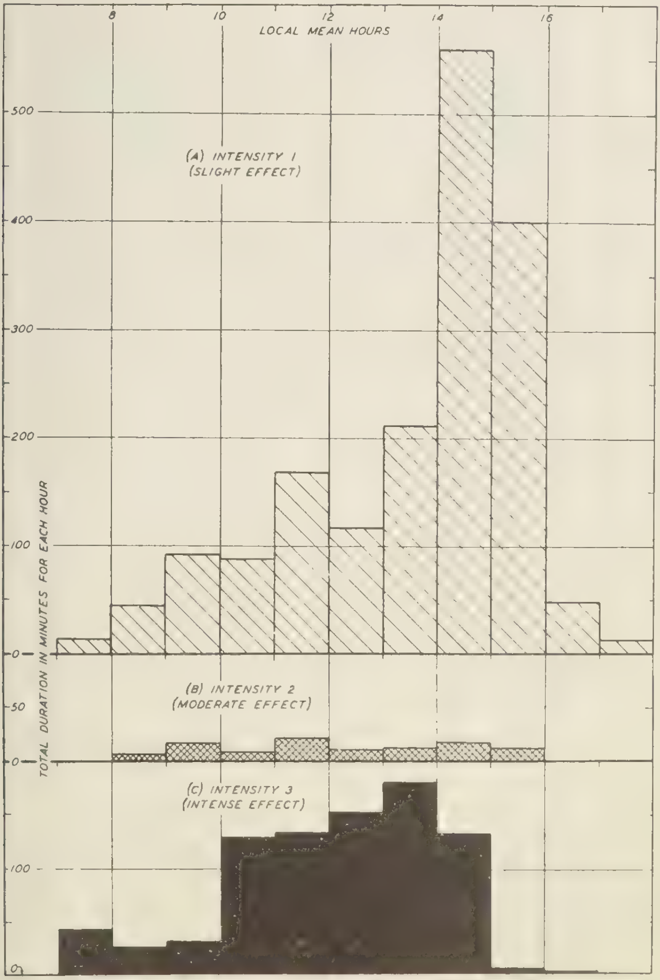


FIG. 8—TOTAL DURATION OF RADIO FADE-OUTS FOR HOURLY INTERVALS, HUANCAYO MAGNETIC OBSERVATORY, JULY 1, 1935, TO FEBRUARY 28, 1937
[SHOWS PRESENCE OF FADE-OUTS DURING DAYLIGHT HOURS ONLY, WITH GREATEST PERIOD OF FADE-OUT NEAR NOON]

TABLE 1 —*Radio fade-outs recorded at the Huancayo and Watheroo magnetic observatories*

Date		GMT Begin		GMT End		Intensity	Remarks[a]	
		h	m	h	m		h	m
Huancayo Magnetic Observatory, July 1935 to February 1937								
1935								
July	6	14	11	14	13	2	*14	08
	7	16	45	16	50	2		
	9	13	45	14	12	1		
	12	18	45	18	54	3		
Sep	11	14	00	14	26	1		
	13	16	30	16	33	3	16	30
	27	12	48	12	50	3	12	48
	29	20	46	21	10	1	20	55
Oct	28	18	38	18	58	1		
Nov	2	19	20	19	27	2		
	3	14	38	14	44	1		
	3	15	23	15	30	1		
	4	20	20	20	27	2		
	4	19	16	19	25	2		
	8	16	46	18	22	1		
	15	18	38	19	20	1		
	18	16	55	17	06	3	17	55
	19	15	31	15	32	1		
	19	20	44	20	46	1		
	28	18	52	19	50	1		
	28	20	06	21	20	1		
	29	14	10	14	18	2	14	05
	29	20	58	21	02	3		
	30	18	52	19	25	3	18	55
Dec	10	18	45	19	00	1		
	12	19	20	21	15	1		
	14	19	28	21	05	1		
	17	16	10	16	17	3	16	15
	23	17	40	18	55	3	17	40
	26	16	15	16	40	1		
	28	18	55	19	45	1		
	29	19	15	19	17	1		
1936								
Jan	1	16	44	16	48	3		
	6	16	45	16	54	3		
	15	19	18	19	42	1		
	18	14	47	14	49	1		
	24	15	43	15	45	2		
	25	18	15	18	20	3		
	25	20	10	20	15	2		
	26	15	30	15	41	1		
	26	20	58	21	07	1		
Feb	6	13	42	13	45	1		
	6	15	17	uncertain		3	15	20
	8	13	33	13	48	3	13	28
	9	12	38	12	43	1		
	11	13	58	14	13	1		
	14	15	17	16	03	3	*15	18
	16	16	00	16	20	3	15	50
Mar	1	17	11	17	16	1		
	4	19	52	20	02	3	19	56
	18	18	07	18	17	3		
	19	18	53	18	59	2		
	20	14	58	15	10	1		
	20	17	50	18	34	1		
	21	17	18	17	39	1		
	22	18	50	19	13	1		
	23	15	39	15	51	3	15	45
Apr	6	13	52	14	01	3	*13	55
1936								
Apr	8	16	45	17	42	3	*16	45
	25	16	57	17	00	2	16	53
May	8	15	20	15	22	3	15	20
	14	17	47	17	48	½	17	52
	25	12	35	12	42	3	*12	35
	28	14	05	14	08	3	*14	00
	28	17	57	18	26	3	*18	00
June	9	13	11	13	25	1		
	9	14	21	14	38	3	*14	24
	9	16	10	16	35	1	15	55
	9	18	59	19	10	3	19	00
	9	19	48	19	58	1		
	10	16	26	16	28	3		
	10	20	54	uncertain		3	*20	55
	11	12	30	12	31	½	12	30
	16	13	30	13	31	½	*13	30
	16	17	16	17	17	1	17	15
	16	18	03	18	04	2	*18	00
	19	19	44	19	46	1	19	38
July	15	13	27	13	29	2	13	25
Aug	4	17	27	17	29	½	17	27
	8	17	25	17	26	½	17	25
Sept	4	12	39	12	39	½	12	38
	29	15	12	15	14	2		
Oct	9	14	30	14	36	2	14	24
	16	17	32	17	50	3	17	35
	16	19	37	uncertain		1		
	21	15	37	15	43	3	*15	35
	21	15	46	15	52	3		
	24	18	04	18	17	1		
	31	13	15	13	25	1		
Nov	6	16	10	17	01	3	*16	10
	7	14	50	15	30	3	14	50
	7	16	10	16	45	1		
	8	17	40	17	50	2		
	8	18	18	18	30	3	18	19
	10	16	58	17	00	1		
	15	14	47	15	41	1		
	15	15	51	16	35	1		
	16	15	00	15	37	3	15	00
	19	13	25	13	29	3		
	24	16	24	16	30	2		
	24	17	00	17	50	3	17	10
	24	19	20	19	46	3	*19	14
	25	19	30	19	41	3	19	25
	26	12	33	12	34	1		
	26	14	30	14	30	½		
	26	16	22	16	55	1		
	26	17	48	18	44	3	*17	50
	26	19	22	19	33	3		
	26	22	22	22	24	1		
	27	16	50	16	57	3	16	51
	28	15	05	15	10	3		
	28	19	00	20	15	1		
	29	15	43	16	08	3	15	47
	29	18	15	18	25	1		
	29	18	43	19	42	1		
	29	20	00	20	50	1		
Dec	1	18	41	18	45	2		

[a] Greenwich mean time of nearly coincident fade-outs reported by J. H. Dellinger (see Terr. Mag., 42, 49-53 (1937)); those preceded by an asterisk are given by Dr. Dellinger as more intense effects

TABLE 1—*Radio fade-outs recorded at the Huancayo and Watheroo magnetic observatories*—Concluded

Date	GMT Begin	GMT End	Intensity	Remarks[a]	Date	GMT Begin	GMT End	Intensity	Remarks[a]
1936	*h m*	*h m*		*h m*	*1937*	*h m*	*h m*		*h m*
Dec 3	12 09	12 45	3	12 10	Jan 9	12 34	12 39	1	
12	14 45	15 02	1		12	18 50	20 02	1	
13	17 45	18 12	1		13	19 30	20 30	1	
13	19 23	19 40	1		14	19 56	21 02	1	
15	19 03	19 36	1		19	18 40	18 45	3	
16	18 45	18 55	1		21	16 36	16 40	2	
16	19 33	19 35	1		21	17 59	18 02	1	See [b]
21	18 18	18 23	3	18 20	Feb 1	19 27	19 41	3	
24	14 14	14 16	1		5	16 39	16 42	2	
24	22 00	22 12	1		9	19 03	19 11	1	
25	15 02	15 06	2		10	19 22	20 15	1	
25	18 58	19 12	1		12	20 08	21 00	1	
26	15 15	15 27	3		20	15 43	15 50	1	
26	19 33	20 02	3		23	14 37	14 38	1	
27	19 25	20 44	1						
29	19 30	19 32	1						
31	13 47	13 51	2	See [a]					

Watheroo Magnetic Observatory, October 1936 to February 1937

Date	GMT Begin	GMT End	Intensity	Remarks[a]	Date	GMT Begin	GMT End	Intensity	Remarks[a]
1936	*h m*	*h m*		*h m*	*1936*	*h m*	*h m*		*h m*
Oct 7	03 36	uncertain	3		Dec 13	02 08	02 45	1	
Nov 24	03 57	04 00	1		17	03 15	uncertain	1	
24	04 57	05 05	1		25	03 40	04 25	1	
25	04 35	05 15	3		25	08 53	08 57	3	
26	04 10	05 14	3		26	04 19	05 51	1	
26	07 06	07 37	3		29	05 03	05 50	1	
26	08 58	09 13	3	09 00	31	03 45	03 55	1	See [c]
27	04 50	05 12	3		*1937*				
27	07 46	08 02	3		Jan 13	04 54	uncertain	3	
28	00 49	01 00	1		19	00 52	00 54	2	
29	01 30	01 36	1		23	02 50	03 24	1	
Dec 4	04 17	06 38	1		23	04 26	07 00	1	
5	04 30	04 46	1		24	04 03	05 22	3	
5	06 00	06 20	1		26	07 57	08 32	3	
5	07 02	07 07	1		27	02 27	03 09	3	
6	07 33	07 35	1		Feb 2	01 40	02 24	1	
6	07 45	07 50	1		2	03 26	04 00	1	
6	08 15	uncertain	1		2	04 34	06 07	1	
10	01 50	uncertain	1		4	04 15	uncertain	1	
11	01 59	02 08	2		13	02 47	uncertain	3	
11	02 45	03 30	1		14	09 07	uncertain	1	
11	04 39	04 43	1		16	09 18	09 22	3	

[a]No records at Huancayo from January 22 to 31, 1937.
[b]Reports quoted of J. H. Dellinger extend through December 1936 only.

occurs with the greatest frequency and intensity within about 30° or 40° of the sub-solar point—these limits probably depend to a great extent upon the intensity of the source. It seems desirable that records from two widely separated stations should be compared to ascertain whether the most intense effects occur at the sub-solar point as should be expected from the eruption-source hypothesis and as is indicated from the foregoing data.

The closeness of coincidence of the effect as observed by independent and widely separated observers has been frequently mentioned [1, 3, 4]. It was thought worth while to examine this point by comparison of the Huancayo data with those of Dellinger. This comparison is possible

for 52 fade-outs as shown in Figure 9. The exactness of coincidence is quite remarkable and leaves utterly no doubt of the widespread character

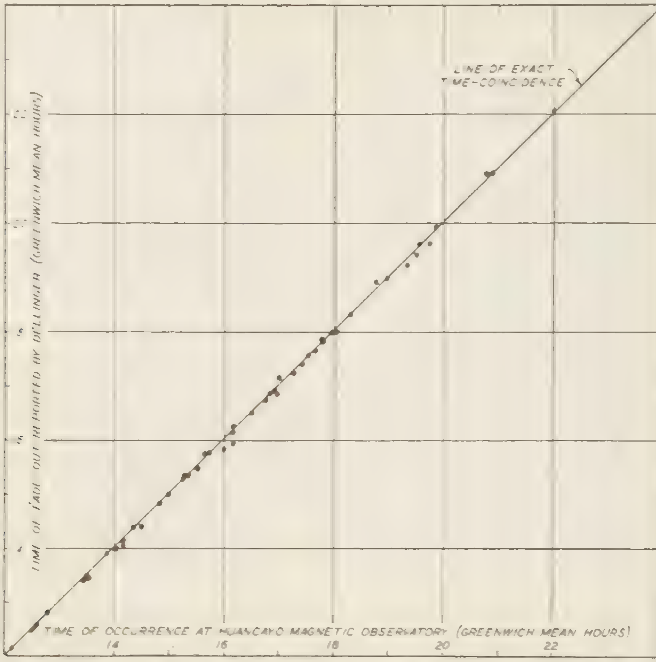


FIG. 9—COINCIDENCE OF TIME OF COMMENCEMENT OF 52 OBSERVED RADIO FADE-OUTS AT HUANCAYO MAGNETIC OBSERVATORY AND THOSE REPORTED BY DELLINGER, JULY 1, 1935, TO DECEMBER 31, 1936

of the effect. Coincidences were apparent for all the effects reported by Dellinger [1] during the sunlit hours at Huancayo (12^h through 21^h GMT) except those noted in Table 2. Of these, no trace of a fade-out could be detected in ten cases while no record was available at Huancayo in four others. In the fifteenth case, a distinct fade-out occurred at Huancayo at $16^h 55^m$ GMT instead of $17^h 55^m$ GMT, suggesting an error in tabulation. It is probable that in the ten cases of disagreement the reports may have come from points closer to the sub-solar point, or that some other disturbance may have been mistaken by the observer

TABLE 2—*Reports by Dellinger for which no fade-outs observed*[a] *at Huancayo Magnetic Observatory*

Date	GMT		Date	GMT		Date	GMT	
1935-6	*h*	*m*	*1936*	*h*	*m*	*1936*	*h*	*m*
Nov 18	17	55[b]	Jun 3	16	35[c]	Jun 19	17	30
Apr 8	14	50	3	18	25[c]	19	20	18
9	13	20	9	17	50	Aug 5	16	07[c]
25	14	27	17	12	48	Sep 3	17	14[c]
May 30	17	30	19	16	20	Nov 3	18	55

[a]Fifty-two coincident fade-outs were observed during daylight hours at Huancayo.
[b]Fade-out at Huancayo at $16^h 55^m$.
[c]No record available from Huancayo.

for the fade-out effect. It is not likely that the method used at Huancayo would fail to disclose a fade-out effect as its sensitivity when applied to weak multiple reflections is great. Neither does the displacement of the most intense effect away from the sub-solar point seem probable if the eruption-source hypothesis is accepted. Of the 15 cases starred in Dellinger's report as more intense effects during the daylight hours at Huancayo, twelve were noted at Huancayo as intensity 3, two as intensity 2, and one as intensity 1/2—the last occurred June 16, 1936, at $13^h\ 30^m$ GMT. This indicates excellent agreement.

The data of Table 1 show that the duration of most fade-outs is very short, being in the order of a few minutes in length. This is illustrated in Figure 10 where the percentage of fade-outs at Huancayo, which last for the time interval shown along the abcissa, is plotted. It will be seen that more than 60 per cent of the fade-outs are less than 15 minutes in duration. The more intense fade-outs tend toward slightly longer duration than the weaker effects. Only a few cases have exceeded one hour in length.

The evidence presented above has demonstrated that the fade-out effect must be an absorption of the radio wave in the region below about 100 km. The mechanism appears to be an increase in ion-density in this region of high collisional frequency, leading to the dissipation of radio waves which usually penetrate the region below about 100 km without

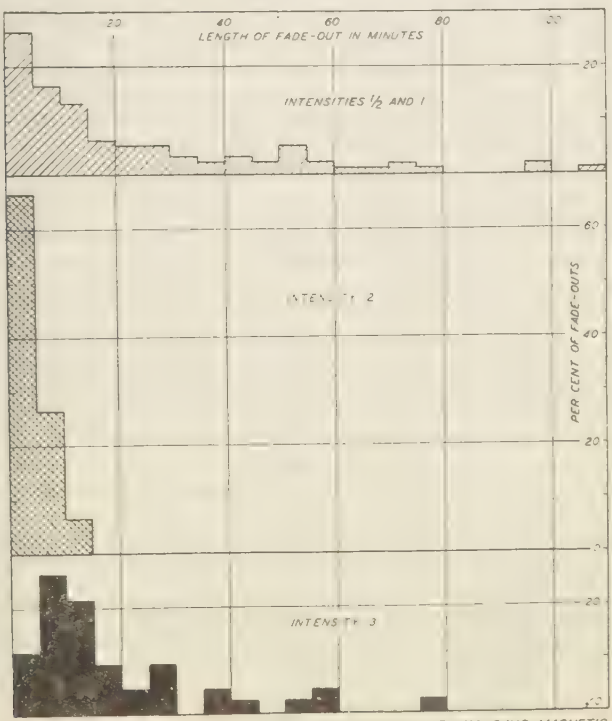


FIG. 10—DURATION OF RADIO FADE-OUTS OBSERVED AT HUANCAYO MAGNETIC OBSERVATORY, JULY 1, 1935, TO FEBRUARY 28, 1937

appreciable loss. Best, Ratcliffe, and Wilkes [7] have shown that the ionization of the region from about 60 to 100 km is responsible for the reflection of very low radio-frequencies. Taking into account the mechanism involved in the reflection of long waves, one immediately expects that low radio-frequency signals should increase in intensity during radio fade-outs, if the transmission-path passes near the sub-solar point. Bureau [8], observing the intensity of atmospherics on low radio-frequencies, has noted just such an increase which may be attributed to improved transmission-conditions during the radio fade-out as a consequence of increased ionization in this region above about 60 and below 100 km.

In summarizing the results of this investigation, we are in agreement with the points made by Dellinger in his discussion of this effect, except as concerns the periodicity of the effect. Fade-outs appear only in the sunlit hemisphere, and are most intense within about 30° of the sub-solar point. The correlation between monthly numbers of fade-outs and sunspots is $+0.53\pm0.10$ for the data from Huancayo. The evidence presented appears to support Dellinger's hypothesis of the origin of these effects in the bright chromospheric eruptions, and many actual coincidences have been established. There is a strong tendency for fade-outs to be grouped—when one appears it is often followed by a series of fade-outs, which occur around the Earth in the sunlit hemisphere. The beginning of a fade-out is essentially coincident at all stations within the probable limit of time-determination. The duration of fade-out is short —more that 60 per cent of fade-outs last less than 15 minutes. The data are not yet sufficient to establish any tendency of recurrence or quasi-recurrence. The effect appears to be an absorption of the radio signal at a level below 110 km. When the evidence of Bureau on long waves is considered, together with the determination of long-wave reflecting heights by Best, Ratcliffe, and Wilkes, it is seen that the lower limit of the effect must extend down to about 60 km. Therefore it may be supposed that the absorption occurs in the region of high collisional frequency between 60 and 100 km, because of the increase of ion-density in this region arising from absorption of ultra-violet radiation from chromospheric eruptions.

We wish to make acknowledgment to Dr. J. A. Fleming, Director of the Department of Terrestrial Magnetism, for his constructive suggestions and appreciation of the importance of the problem, and to S. L. Seaton of the Watheroo Magnetic Observatory and H. E. Stanton of the Huancayo Magnetic Observatory who have been the observers responsible for the splendid series of data obtained.

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THE DISTRIBUTION OF ATMOSPHERIC OZONE IN EQUILIBRIUM WITH SOLAR RADIATION AND THE RATE OF MAINTENANCE OF THE DISTRIBUTION

By Oliver R. Wulf and Lola S. Deming

In two earlier articles[1] the authors have shown that if atmospheric ozone is considered as existing in a photochemical steady state depending on solar radiation, calculations involving certain assumptions regarding the absorption-coefficients yield a distribution of the ozone with height which is sufficiently similar to the distribution that is deduced from experimental observations to suggest that the photochemical picture is adequate to account for atmospheric ozone. At the end of the first paper the disturbance of the steady state by atmospheric circulation was briefly discussed, and it was pointed out that the known variations in the existing vertical ozone path over any point on the Earth's surface might be explained as due to such disturbance. In order to estimate the quantitative importance of circulation in the photochemical picture, it is necessary to have some idea of the rates at which the steady state is maintained at the various heights. It is one of the purposes of the present paper to estimate the approximate values of these rates.

In the expression for the distribution used in the calculations of the previous two papers, equation (14) of the original article, the value of the numerical constant $k_f\ k_d$ was taken as determined from the known total ozone. It was shown that this value was dependent on the absorption-coefficient curves for oxygen and ozone. This constant is the ratio of two specific reaction-rates. It was also shown that for the absorption-coefficient curves that were employed, the value required for this ratio was somewhat lower than that indicated by laboratory experiment. It seemed, however, that the wide differences between laboratory experiment and the atmosphere might well account for this. It was pointed out in our second article that an absorption-coefficient curve falling less deeply in the region of 2000Å than those of Cases A and B of Figure 1 would lead to an increase in the value of the numerical constant. The early measurements of Meyer[2] point indeed toward such a curve, but while Meyer's values agree fairly well with more recent ones in the region of the ozone maximum (2500Å), his values are high in the region of 3000Å compared with those now believed to be correct. In view of this it seems possible that his values in the 2000Å-region may also be too high.

However, in view of the fact that the calculation of the rates at which the steady state is maintained in various heights is dependent in an important way upon the character of the absorption-coefficient curve, it seems wise to consider cases that fall less rapidly in the 2000Å-region, and, perhaps best, one that leads to the use of a numerical value for the

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[2] Ann. Physik, **12**, 849-859 (1903).

above-mentioned ratio which is in accord with the indications of laboratory experiment. Recently Eucken and Patat[3], in a detailed study of the photochemical ozone equilibrium, have obtained the following values for this constant: At 0°C, 1.8×10^{-3} per mm Hg; at -30°C, 8×10^{-3} per mm Hg; and at -60°C, 4.9×10^{-2} per mm Hg. These converted into our units are, respectively, 0.5×10^{-19}, 2×10^{-19}, and 1.1×10^{-18}. It will be seen that these values are of the order of magnitude mentioned in our original paper as being indicated by earlier experiments. For the purpose of the present work, with due regard for the uncertainty of the atmospheric temperature throughout the heights of importance in the ozone-distribution, it seems that 10^{-19} may be taken as an approximate value for this constant in view of the results of Eucken and Patat. Certainly this will illustrate the character of the difference that a considerable increase in the value of the numerical constant causes.

In choosing a third representation of the absorption-coefficient curves as shown in Figure 1, which we will call Case *C*, we have followed the values of Ny and Choong[4] for ozone to the limits of their measurements at 2150Å, and beyond this have employed a smooth extrapolation of such character that the above-mentioned value of the numerical constant in equation (14) leads to roughly the known vertical path of ozone in the

[3] Zs. physik. Chem., B, 33, 459-474 (1936).
[4] C. R. Acad. sci., **196**, 916-918 (1933).

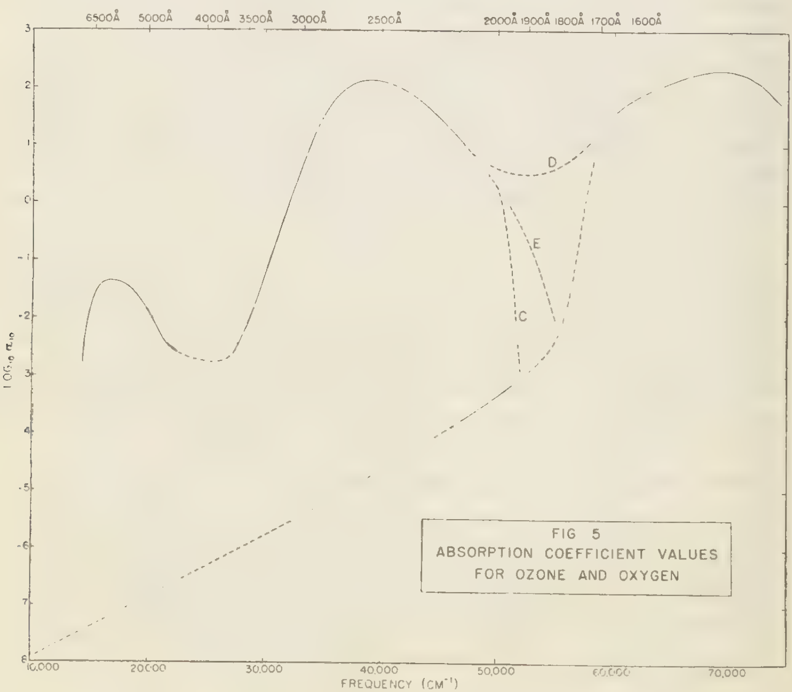

FIG 5
ABSORPTION COEFFICIENT VALUES
FOR OZONE AND OXYGEN

atmosphere. The particular shape of the curve in this region located nearly centrally between the ozone maximum and oxygen maximum is of real importance in the calculations. If the curve finally drops steeply to the oxygen values in the vicinity of 2000 to 1900Å, then we still have radiation absorbed by oxygen penetrating deeply into the atmosphere. If, however, values such as those found by Meyer are correct, with the minimum value of $\alpha = 8$, this circumstance would act strongly to prevent any radiation absorbed by oxygen penetrating deeply into the atmosphere.

In order to cover the range of possibilities in making these calculations, we have chosen three new representations of the absorption-coefficients in this intermediate region, labeled C, D, and E, respectively, and it is the further purpose of the present paper to give the distributions to which these cases lead, using otherwise the same data as in the two preceding articles[5]. Case E is intermediate to Cases C and D. These are shown in Figure 5, where the range of absorption-coefficients used may be seen at a glance. For Cases C and E a value of 10^{-19} has been used for the numerical constant in equation (14) as mentioned above. For Case D, however, a value of 10^{-18} has been employed in order to keep the area under the distribution-curve approximately equal to the known total ozone in the vertical path.

In carrying through the present work, we have tried to improve the approximate methods employed where possible and to represent the measured values somewhat more closely in the absorption-coefficient curves[6]. Slight alterations were made in the latter in the regions of 19,000 cm^{-1} and 30,000 cm^{-1}, and an interpolation was made in the region 22,000 to 29,000 cm^{-1}. The most important change in the methods of calculation has been the abandoning of the sharp division between the oxygen and the ozone regions of absorption used in the earlier work. This sharp division, though reducing considerably the labor involved, was a rather crude approximation. In the present work, for all frequencies absorbed appreciably by both ozone and oxygen, Figure 2 of our first article was abandoned, and a direct calculation of the increment of light absorbed by oxygen over each frequency-range and for each successive interval of height was made, just as in the case of ozone but using the same oxygen-distribution as was used in computing Figure 2 of our original article. In this way very low frequencies continue to play a small rôle in the oxygen-absorption. The extrapolation which we have used of the known oxygen values to low frequencies can be seen in Figure 5. In all probability this extrapolation lies, if anything, above the actual but as yet unknown curve, and the influence of oxygen-absorption will thus be even less than it proves to be on this basis. Molecular dissociation does not occur, morever, below 41,000 cm^{-1} (heat of dissociation is slightly under 5.1 volts; see, for example, Jevons, "Review of band spectra," Phys. Soc. London, 1932), and only down to this limit were the various increments of absorption taken as contributing to Q_2. But the absorption caused by frequencies lower than this is not without effect, since it represents a depletion of radiation which is being absorbed in a photochemically active way by ozone. These increments of absorption by oxygen entered

[5]The Table and Figures of this article will be numbered as continuations from the two preceding articles.

[6]For a review of the work on the absorption-coefficients see Penndorf, Beiträge zum Ozonproblem, Veröffentlichungen des Geophysikalischen Instituts der Universität, Leipzig, 1936, also Vassy, Sur quelques propriétés de l'ozone et leurs conséquences géophysiques, Thesés. Université de Paris, 1937.

TABLE 3—*Calculated*

s	n_2	n_M	Case C ($k_f/k_d = 10^{-13}$)			
			Q_2	Q_3	n_3	t
7.00×10^{6}	2.86×10^{12}	5.00×10^{13}	1.17×10^{13}	5.86×10^{11}	1.36×10^{7}	2.91×10^{-1}
6.00×10^{6}	1.55×10^{13}	2.10×10^{14}	8.13×10^{12}	[illegible]$.32\times10^{12}$	1.71×10^{8}	5.26
5.00×10^{6}	8.39×10^{13}	9.30×10^{14}	1.19×10^{13}	5.74×10^{13}	1.34×10^{9}	2.81×10
4.25×10^{6}	2.99×10^{14}	2.85×10^{15}	1.17×10^{13}	1.40×10^{14}	6.58×10^{9}	7.00×10
3.75×10^{6}	6.92×10^{14}	6.10×10^{15}	2.00×10^{13}	4.08×10^{14}	1.97×10^{10}	1.23×10^{2}
3.25×10^{6}	1.62×10^{15}	1.30×10^{16}	3.24×10^{13}	1.12×10^{15}	5.90×10^{10}	2.27×10^{2}
2.75×10^{6}	3.75×10^{15}	2.75×10^{16}	5.75×10^{13}	2.85×10^{15}	2.04×10^{11}	4.43×10^{2}
2.25×10^{6}	8.75×10^{15}	5.90×10^{16}	8.42×10^{13}	3.05×10^{15}	1.39×10^{12}	2.06×10^{3}
1.75×10^{6}	2.04×10^{16}	1.28×10^{17}	7.10×10^{13}	2.94×10^{15}	6.13×10^{12}	1.07×10^{4}
1.25×10^{6}	4.74×10^{16}	2.75×10^{17}	2.77×10^{13}	3.37×10^{15}	1.06×10^{13}	4.77×10^{4}
0.75×10^{6}	1.10×10^{17}	6.00×10^{17}	2.70×10^{12}	2.22×10^{15}	8.04×10^{12}	3.70×10^{5}

Remarks regarding notation:

s in each case is the mid-point of the interval of height under consideration; $s=0$ at 20 km above Earth's surface.

n_2, n_M, n_3 denote the number of oxygen molecules per cc, the total number of molecules per cc, and the number of ozone molecules per cc, respectively.

Q_2 and Q_3 designate quanta absorbed per second by the respective constituent over an interval of height Δs.

t in seconds is the approximate time of half-restoration of the ozone (see text).

thus simply as deductions made with each step in height, reducing the intensity of the particular frequency-range though not contributing to the photochemical action.

In the vicinity of 50,000 cm^{-1} (see Figure 5), where the curve of the

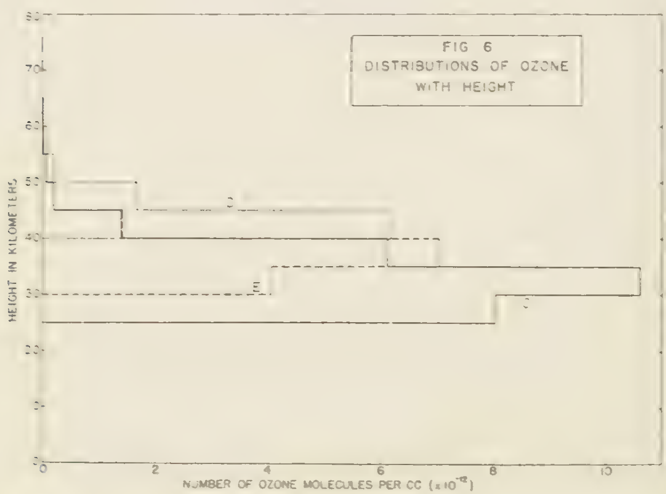

FIG 6
DISTRIBUTIONS OF OZONE WITH HEIGHT

distributions and rates with height

Case E ($k_f/k_d = 10^{-19}$)				Case D ($k_f/k_d = 10^{-18}$)			
Q_2	Q_3	n_3	t	Q_2	Q_3	n_3	t
1.17×10^{13}	5.87×10^{11}	1.36×10^{7}	2.92×10^{-1}	1.17×10^{13}	4.42×10^{12}	1.04×10^{5}	2.22
8.13×10^{12}	7.35×10^{12}	1.71×10^{8}	5.25	8.13×10^{12}	3.00×10^{13}	6.94×10^{8}	2.13×10
1.13×10^{13}	5.64×10^{13}	1.30×10^{9}	2.88×10	1.15×10^{13}	1.89×10^{14}	4.45×10^{9}	9.71×10
1.21×10^{13}	1.42×10^{14}	6.68×10^{9}	6.88×10	1.19×10^{13}	4.52×10^{14}	2.19×10^{10}	2.29×10^{2}
1.99×10^{13}	4.07×10^{14}	1.97×10^{10}	1.23×10^{2}	2.69×10^{13}	1.45×10^{15}	7.68×10^{10}	3.57×10^{2}
3.24×10^{13}	1.12×10^{15}	5.93×10^{10}	2.29×10^{2}	3.23×10^{13}	2.82×10^{15}	2.38×10^{11}	9.21×10^{2}
5.76×10^{13}	2.85×10^{15}	2.04×10^{11}	4.43×10^{2}	5.26×10^{13}	3.19×10^{15}	1.67×10^{12}	3.96×10^{3}
8.69×10^{13}	3.07×10^{15}	1.42×10^{12}	2.04×10^{3}	3.29×10^{13}	2.71×10^{15}	6.19×10^{12}	2.34×10^{4}
8.99×10^{13}	3.24×10^{15}	7.04×10^{12}	9.75×10^{3}				
4.02×10^{12}	1.29×10^{15}	4.06×10^{12}	1.25×10^{5}				

Remarks regarding notation:

n_2, n_M, n_3 denote the number of oxygen molecules per cc, the total number of molecules per cc, and the number of ozone molecules per cc, respectively.

Q_2 and Q_3 designate quanta absorbed per second by the respective constituent over an interval of height Δz.

t in seconds is the approximate time of half-restoration of the ozone (see text).

ozone absorption-coefficients approaches the curve for oxygen, the increment of light absorbed by ozone is small compared to that absorbed by oxygen, this being due to the fact that n_2 is so very much greater than n_3. For shorter wave-lengths the question as to what the absorption of ozone may be is unimportant for the present problem, since oxygen absorbs practically all of the available radiation owing to its own high absorption-coefficients and its very high relative concentration.

The results of the distribution-calculations for these three cases are shown in Table 3 and Figure 6. The three curves have areas comparable with the known atmospheric ozone as can be seen by roughly estimating the area under them and recalling that the vertical ozone-path contains about 10^{19} molecules over a square centimeter. As in our first article, no effort has been made to choose a numerical value of the constant such that the areas under the curves correspond exactly to the actual vertical ozone-path.

It was pointed out in our second paper that the effect of such absorption-coefficients as those assumed in Cases E and D, "would be to displace to higher altitudes the major portion of the distribution-curve and to reduce the area under it, the latter effect permitting the use of a higher value of the numerical constant (k_f k_d) in equation (14), to obtain the correct total ozone-value." These two points are illustrated in Figure 6, the change in height being very pronounced, while the effect on the area can be seen from the decrease in passing from Case C to Case E, and from the higher numerical value of the constant employed in Case D. At first sight D (and less so E and C) would seem too high to correspond to the distribution of ozone as it is at present known from observation.

We will, however, later remark briefly on the possibility of such a distribution with a lower value of the constant, provided that the principal portion of atmospheric ozone lies in protected regions and does not really exist in a photochemical steady state.

There is a further circumstance which should be noted. The value of the constant in equation (14) decreases with increasing temperature, as was illustrated by the data cited from Eucken and Patat above. Herein lies a factor which conceivably could result in holding the principal part of photochemical ozone to low altitudes even with relatively high values of the absorption-coefficient in the region of 2000Å such as is represented by Case *D*. If, for example, we were to assume a temperature-difference with height[7] such as 0°C at 50 km, −30°C at 35 km, and −60°C at 20 km, the appropriate values of the constant would vary over this range, increasing by a power of ten in passing from 50 km to 20 km. This would tend to depress the ozone in the higher altitudes and to raise it in the lower ones, as would be required to bring our Case *D* more nearly into accord with observation.

Coming now to the question of how rapidly the ozone-distribution will be restored if disturbed at any height, we may derive an expression for such rate from the equations describing the chemical processes occurring, as was done in formulating equation (11) of our first paper. Thus, under the conditions stated there, from equation (3) we see that the rate of formation of ozone is equal to

$$+\frac{\mathrm{d}n_3}{\mathrm{d}t} = k_f n_1 n_2 n_M \tag{15}$$

The expression for the rate of ozone-decomposition is obtained from equations (4) and (5)

$$-\frac{\mathrm{d}n_3}{\mathrm{d}t} = a_3 n_3 q_3 + k_d n_1 n_3 \tag{16}$$

Assuming now simply that there does always exist a steady state with respect to oxygen atoms, we have the value for n_1, given by equation (10)

$$n_1 = (2Q_2 + Q_3)/(k_f n_2 n_M + k_d n_3) \tag{10}$$

However, since we are now considering conditions removed from equilibrium, the quantities Q_2 and Q_3 do not possess the values which they have when the ozone-concentration is at its equilibrium-value. To designate this in rate-expressions such as the one to follow, these symbols will be designated Q'_2 and Q'_3. If ozone is removed or destroyed by some means at a particular height, during the course of recovery Q'_2 will be somewhat larger than it is under equilibrium-conditions, while Q'_3 will increase from zero and will approach its value under equilibrium-conditions as the concentration of ozone, n_3, approaches its equilibrium-value. The resultant rate of recovery is evidently given by the difference between the rate of formation and the rate of decomposition written above. Calling this resultant rate *R* and substituting the value for n_1 into the two expressions, we have

[7]Compare Vassy, C. R. Acad. sci. **203**, 1363-1365 (1936).

$$R=\left[\frac{k_f n_2 n_M - k_d n_3}{k_f n_2 n_M + k_d n_3}\right] 2Q'_2 - \left[1-\frac{k_f n_2 n_M - k_d n_3}{k_f n_2 n_M + k_d n_3}\right] Q'_3$$

$$=\left[1-2\frac{k_d n_3}{k_f n_2 n_M}+2\left(\frac{k_d n_3}{k_f n_2 n_M}\right)^2-\ldots\right]2Q'_2-\left[2\frac{k_d n_3}{k_f n_2 n_M}-2\left(\frac{k_d n_3}{k_f n_2 n_M}\right)^2+\ldots\right]Q'_3 \tag{17}$$

This expression is rather interesting in form. The coefficient of $2Q'_2$ contains n_3, but the other quantities therein are known, and n_3, during recovery, cannot of course be greater than the equilibrium-value. Now the terms following unity in the coefficient of $2Q'_2$ prove to be small compared to unity, even at equilibrium. At the outset of recovery when no ozone is present, the rate of recovery is equal to $2Q'_2$, the second of the two terms being, of course, zero. The value of $2Q'_2$ will not be its equilibrium-value as given in Table 3, but will be somewhat greater than this, owing to the absence of ozone, which at equilibrium-conditions takes some radiation which could otherwise be absorbed by oxygen and which is so absorbed at the outset of recovery. It appears that $2Q_2$ may be taken as a somewhat conservative estimate of the rate of recovery at the outset. Evidently the second term will immediately begin taking on appreciable values as n_3 increases, equalling finally the first term at equilibrium. Now, of the terms in the coefficient of Q'_3, only the first one is of much importance, the second being about one-hundredth as large as the first even at equilibrium. This first term of the coefficient of Q'_3 contains n_3 in the first power, and Q'_3 also contains n_3 in the first power. If we consider then only the first term of the coefficient, we find that the rate of recovery of the ozone decreases from the outset approximately as the square of n_3. The first of the two terms in the expression for the rate may be treated as roughly constant. Hence $2Q'_2$, where Q'_2 is taken as the value at equilibrium, should give an approximate idea of the rate at which the first portion of the recovery occurs, and if using it we compute the time required for half the ozone to be restored, the value so obtained will probably indicate with sufficient accuracy whether the restoration is of the order of minutes or days. The approach of n_3 to equilibrium is, of course, asymptotic, and hence there is no point in inquiring the time required to restore complete equilibrium. In Table 3 the columns labeled t give this time of half-restoration of the ozone calculated in the manner just described. It will be seen that for all three cases equilibrium is restored very rapidly (of the order of minutes or less) in the altitudes lying well above the maximum of the distribution, and that here the distribution can probably be considered as steadily maintained in the presence of solar radiation. In the vicinity of the maximum, however, this condition changes, and thereafter, the time required for noticeable restoration is of the order of days. Thus in the altitudes below the maximum, a disturbance of the ozone-equilibrium will presumably persist until further disturbances occur, and thus this will be a region subject to alteration by such effects as transport through atmospheric circulation. We hope to discuss in a later paper the condition of ozone carried into levels below those of the photochemical equilibrium, which we have called protected regions. Some photochemical decomposition occurs here also, of course, since radiation of frequencies absorbed appreciably by ozone reaches the surface of the Earth.

In conclusion, the authors wish to point out that, assuming photochemical origin, one of two different views might be taken with regard to the total existing atmospheric ozone: First, that it consists principally of ozone which is at least roughly in equilibrium with solar radiation at all heights, or second, that it consists largely of ozone carried by transport into regions where it is considerably protected from solar radiation, the fraction in equilibrium with solar radiation being small and confined to the higher altitudes. Here the choice influences greatly any conclusions drawn from calculations made on the photochemical steady state. It may be that atmospheric ozone is chiefly of photochemical origin and yet that observations on the existing distribution with height give little idea of the distribution of the ozone existing in equilibrium with solar radiation.

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TERRESTRIAL MAGNETISM AT TSINGTAO DURING THE SOLAR ECLIPSE OF JUNE 19, 1936[1]

By Chao-Yang Liu

The solar eclipse which occurred June 19, 1936 was total, but the phase seen at Tsingtao was only partial (being 0.56 of the solar diameter). The calculated times for this eclipse referred to 120° east meridian time were: Beginning of the eclipse, $12^{h}\ 48^{m}\ 59^{s}$; maximum eclipse, $14^{h}\ 07^{m}\ 26^{s}$; ending of the eclipse, $15^{h}\ 18^{m}\ 29^{s}$.

The sky unfortunately was very cloudy on June 19. No astronomical work could be done. The only photograph we could get was densely overcast. It was taken at $14^{h}\ 32^{m}$.

On the other hand, clouds would certainly not greatly influence the terrestrial-magnetic elements. As we had also prepared a program for the magnetic work, we expected to realize it even though clouds might prohibit astronomical observations. It is generally recognized by theory that, because of close correlation between solar activity and the terrestrial magnetism, a total solar eclipse exerts some effect on the latter. But the degree of this effect can be determined only by actual observations, especially in the central eclipse-zone. For purposes of comparison with these, knowledge of the detailed conditions of the three elements at stations outside of the eclipse-zone, such as Tsingtao, may be profitable.

[1]A paper in Chinese on these data has been published in the Reports of the Commission Chinoise pour l'Observation de l'Eclipse totale du Soleil.

Table 1—*Magnetic elements at Tsingtao Observatory during solar eclipse of June 19, 1936*

120° east meridian	West declination		Intensity magnetogram		120° east meridian	West declination		Intensity magnetogram	
	Obs'd	Magnetogram	Horizontal	Vertical		Obs'd	Magnetogram	Horizontal	Vertical
h m	° ′	° ′	γ	γ	h m	° ′	° ′	γ	γ
2 48	....	4 42.35	30810.4	39725.6	14 12	4 39.80	4 40.96	30802.3	39732.0
51	....	41.84	818.0	724.9	15	40.20	41.11	802.1	731.7
54	....	41 84	810.0	727.4	18	40.30	41.25	800.7	734.9
57	....	42.21	813.5	727.8	21	40 30	41.39	801.9	734.9
3 00	....	41.98	813.5	728.5	24	40.25	41.46	801.9	735.9
03	4 40.70	41.94	815.5	728.5	27	40.20	41.32	802.7	736.3
06	40.55	41.84	819.7	728.8	30	40.20	41.25	802.7	738 1
09	40.45	41.69	824.6	729.2	33	40.35	41.25	804.2	738.4
12	40.60	41.69	825.9	729.2	36	40.65	41.46	805.5	739.2
15	40.60	41.76	825.5	729.5	39	40.75	41.97	804.2	739 9
18	40.60	41.84	823.7	731.3	42	41.15	42.90	805.4	741.7
21	40.45	42.35	825.0	731.7	45	41.45	42.50	806.9	742 4
24	40.45	42.50	833.7	732.0	48	41.75	42.73	804.2	742.7
27	40.40	42.43	837.7	732.7	51	41.75	42.80	802.1	745.2
30	40.35	41.69	843.3	732.0	54	41.75	42.80	801.9	746.3
33	40.05	41.18	845.3	730.2	57	41.55	42.73	802.9	747.0
36	39.75	40.74	851.0	731.7	15 00	41.35	42 58	806.1	749 9
39	39.10	40.30	853.5	731.7	03	41.35	42.35	808.3	750.2
42	38.55	39.64	852.7	732.0	06	41.64	42 38	813.7	750.4
45	37.95	40.05	857.0	732.0	09	42.05	42.94	813.7	750.7
48	38.00	38.98	859.1	730.2	12	42.25	43.31	811.6	752 5
51	38.15	39.19	855.7	728.5	15	42.65	43.32	808.1	752.5
54	38.65	39.19	845.3	728.1	18	42.45	43.73	802.3	753.2
57	38.95	40.37	823.6	725.2	21	42.45	43 52	802.3	753 6
4 00	38.95	40.37	808.5	728.5	24	42.45	43.38	804.2	753 2
03	39.15	40.23	806.5	729.5	27	42 35	43.45	805.8	754 0
06	39.30	40.37	804.6	730.3	30	42.45	43.52	808.1	754 3
09	39.45	40.66	811.7	731.1					

With this object in view, absolute observations for declination were taken at Tsingtao every three minutes from 13^h to $15^h\ 30^m$, June 19. The revolving drum of the recording apparatus of the magnetograph, originally run at the rate of one revolution in about 25 hours, was accelerated so that one revolution was made in two hours. After measurements and calculations the behavior of the terrestrial magnetism during the time of this eclipse is shown by the three components in Table 1.

The observed results for west declination were made by W. K. Hsü.

Table 1 shows that the variations of the terrestrial-magnetic elements during the times of eclipse were rather irregular at Tsingtao. Indeed, a comparatively large storm had begun at as early as $17^h\ 45^m$, June 18. The horizontal intensity reached a maximum at $9^h\ 45^m$, June 19, being about 48.5 gammas lower than the base-line whose value was then 30998.2 gammas. It decreased quickly and attained its minimum at $16^h\ 45^m$, about 219.2 gammas below the base-line. Thus the absolute range for this component was 170.7 gammas. The whole course of this element assumed the form of a "bay." For it increased after a few fluctuations and recovered its original course at about $22^h\ 30^m$. As this storm might not be limited to this locality, one can realize the difficulty of separating the small eclipse-effect[2] from the large variations of this storm, if it occurred also in the central eclipse-zone.

Table 2 shows the tendencies of the three elements before and after the eclipse.

Table 2—*Magnetic values at Tsingtao Observatory before and after those of Table 1*

120° east meridian	West declination Magnetogram	Intensity magnetogram Horizontal	Intensity magnetogram Vertical	120° east meridian	West declination Magnetogram	Intensity magnetogram Horizontal	Intensity magnetogram Vertical
h m	° ′	γ	γ	h m	° ′	γ	γ
8 30	4 32.88	30934.2	39748.9	18 00	4 39.65	30796.4	39774.9
9 00	31.92	928.4	749.9	18 30	39.41	790.6	774.9
9 30	30.82	930.7	749.9	19 00	38.39	786.7	774.9
10 00	32.29	910.9	743.2	19 30	39.48	794.4	773.1
10 30	32.88	866.3	734.5	20 00	38.61	796.4	774.9
11 00	34.86	846.9	725.6	20 30	38.17	815.8	774.9
11 30	39.63	816.0	721.3	21 00	37.43	837.2	773.8
12 00	40.74	800.3	714.2	21 30	38.01	852.2	770.2
12 30	42.28	785.5	722.0	22 00	39.05	852.4	770.2
	Eclipse-period			22 30	37.43	881.8	770.5
16 00	43.31	833.3	764.2	23 00	37.43	874.4	768.4
16 30	41.84	795.5	767.7	23 30	36.85	883.1	767.0
17 00	41.84	786.9	766.3	24 00	37.28	885.7	767.3
17 30	39.65	784.8	774.9				

Tables 1 and 2 are self-explanatory. It is only to be remarked that after midnight June 19 (Greenwich mean day) the three components had become comparatively calm.

One may note also that some irregular oscillations with a few small peaks took place in the interval from 9^h to about 16^h, June 20. This may be considered perhaps as an after-effect of the above-mentioned storm.

[2]The eclipse-effect is always very small; see, for instance, S. Chapman, The effect of a solar eclipse on the Earth's magnetic field, Terr. Mag., **38**, 175-183 (1933).

Tsingtao Observatory,
Tsingtao, China

PROVISIONAL SUNSPOT-NUMBERS FOR MARCH TO MAY, 1937

(Dependent alone on observation at Zürich Observatory and its station at Arosa)

Day	March	April	May
1	*W*154[ac]	*M*140[c]	89
2	154[b]	128	91
3	*E*109[c]	112[d]	77
4	*E*65[cd]	*E*139[c]	56[ad]
5	76	*E*149[c]	59
6	71	114	46
7	*W*105[c]	*M*121[c]	47
8	115[abd]	96	*E*50[c]
9	107	86[ab]	68[d]
10	99	71	*M*103[ac]
11	98	*E*82[c]	99[a]
12	59	62	91
13	41[a]	38	. . .
14	21	. . .	*E*111[cd]
15	20	*E* . . .[acd]	140[ad]
16	*E*23[c]	64	*W*183[c]
17	22	63[a]	184
18	*E*37[ac]	*E*76[c]	158[d]
19	33	*E*94[c]	158
20	. . .[d]	*E*127[c]	177[bd]
21	*E*62[ac]	127[a]	154[aad]
22	*M*74[c]	*M* . . .[bbc]	*E*194[ac]
23	107[d]	144[b]	202
24	. . .[d]	*M*157[bc]	213[a]
25	87	*ME*190[acc]	171
26	80[a]	157	130[a]
27	*M*118[ac]	161	93[a]
28	131	149	71
29	117[a]	123[bd]	*E*83[cd]
30	135[a]	94[b]	103
31	145[a]		98
Means. .	85.0	113.5	116.9
No. days	29	27	30

Mean for quarter January to March, 1937: 115.7 (*78 days*)
Mean for year 1936: 78.2 (*336 days*)

[a]Passage of an average-sized group through the central meridian.
[b]Passage of a large group or spot through the central meridian.
[c]New formation of a group developing into a middle-sized or large center of activity: *E*, on the eastern part of the Sun's disc; *W*, on the western part; *M*, in the central-circle zone.
[d]Entrance of a large or average-sized center of activity on the east limb.

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W. BRUNNER

AVERAGES OF CRITICAL FREQUENCIES AND VIRTUAL HEIGHTS OF THE IONOSPHERE, OBSERVED BY THE NATIONAL BUREAU OF STANDARDS, WASHINGTON, D. C., MARCH AND APRIL, 1937[1]

The following ionosphere data are in continuation of those published for 1934-36 in this JOURNAL[2]. The symbols used are:

h_E = E-region virtual height, kilometers (lowest measured height)

h_{F_1} = F_1-region virtual height, kilometers (lowest measured height)

h_{F_2} = F_2-region virtual height, kilometers (lowest measured height)

f_E = E-region critical frequency, kilocycles per second, ordinary ray

$f^o_{F_1}$ = F_1-region critical frequency, kilocycles per second, ordinary ray

$f^x_{F_2}$ = F_2-region critical frequency, kilocycles per second, extraordinary ray

EST = Eastern standard time (75° west meridian time); add 5 hours for Greenwich time

♯ = Manual meaurements

* = Less than ten measurements with automatic recorder

[1]Communicated by the director of the National Bureau of Standards of the United States Department of Commerce.
[2]T. R. Gilliland, S. S. Kirby, N. Smith, and S. E. Reymer, Terr. Mag., **41**, 379-388 (1936).

TABLE 1—*Ionosphere data, National Bureau of Standards, Washington, D. C.*

EST	h_E	h_{F_1}	h_{F_2}	f_E	$f^o_{F_1}$	$f^x_{F_2}$	h_E	h_{F_1}	h_{F_2}	f_E	$f^o_{F_1}$	$f^x_{F_2}$
			March 1937[a]						*April 1937*			
00			291			7480			325			674
01			299			7230			315			645
02			303			6950			315			615
03			307			6695			321			598
04			291			6330			324			569
05			295			6067			317	1080♯		548
06	...		282	1440♯		6160			267	2150		658
07	...		247	2360♯		8080♯	128*	...	253	2719	4100♯	728
08	126	235	245♯	2850		9600♯	122	246	260♯	3102	4700♯	795
09	125	228	287♯	3190	5050[b]	10360♯	120	234	260♯	3382	4850♯	813
10	121	220	281♯	3485	5350[b]	11100♯	119	222	270♯	3654	5000♯	853
11	122	222	282♯	3663	5450[b]	11780♯	120	222	291♯	3770	5080♯	900
12	123	227	280♯	3750	5700[b]	12300♯	120	225	291♯	3837	5200♯	940
13	123	228	286♯	3715	5500[b]	12360♯	120	234	298♯	3819	5230♯	950
14	125	233	278♯	3618	5600[b]	12300♯	122	237	289♯	3715	5080♯	950
15	126	238	268♯	3420		12200♯	121	242	285♯	3494	4870♯	948
16	127	240	260♯	3060		12140♯	124	242	270♯	3196	4700♯	960
17	...		248	2605		11860♯	128	...	253	2819	4200♯	965
18	...		241	1970♯		11100♯			264	2380♯		985
19			239			10220♯			258	1730♯		953
20			252			9600♯			268			853
21			261			8940♯			287			764
22			272			8260♯			305			717
23			282			7840♯			323			692

[a]The F_2-region was disturbed on the following days, arranged in order of severity of disturbance: March 15-16, 31, 27-28. High virtual heights and low critical frequencies were noted on these days. Where two successive days are given former was the more severely disturbed.
[b]Observations March 31 only. Well-defined F-layer stratification was observed only on March 31.

NATIONAL BUREAU OF STANDARDS,
UNITED STATES DEPARTMENT OF COMMERCE,
Washington, D. C.

AMERICAN *URSI* BROADCASTS OF COSMIC DATA[1], JANUARY TO MARCH, 1937

The data for terrestrial magnetism, sunspots, and solar constant are the same as given in previous tables.

The first three columns of the Table give (1) the magnetic character according to the scale 0-2 of the International Commission of Terrestrial Magnetism and Atmospheric Electricity, (2) the type featuring the day other than normal by the letters *b*, *p*, *o*, and *i* for days marked by bay, rapid pulsations, long-period oscillations, and irregular oscillations, respectively, and (3) the hour and minute of Greenwich mean time marking the beginning of a storm, the end of the storm being indicated in the footnote to the Table. The next two columns give the data relating to sunspots: (1) the number of groups of spots and (2) the total number of

[1]For previous announcements see Terr. Mag., **35**, 184-185 and 252-253 (1930); **36**, 54, 141, 258-259, and 358-360 (1931); **37**, 85-89, 189-192, 408-411, and 484-487 (1932); **38**, 60-63, 148-151, 262-265, 335-339 (1933); **39**, 73-77, 159-163, 244-247, 353-356 (1934); **40**, 111-115, 220-222, 334-336, 449-452 (1935); **41**, 85-87, 207-209, 315-317, 407-409 (1936); and **42**, 89-91 (1937).

Summary American URSI daily broadcasts of cosmic data, January to March, 1937

Date	January								February								March								Date
	Magnetism				Sun-spot		Solar constant		Magnetism				Sun-spot		Solar constant		Magnetism				Sun-spot		Solar constant		
	Character	Type	G. M. T. begin. distur.		Groups	Number	Value	Character	Character	Type	G. M. T. begin. distur.		Groups	Number	Value	Character	Character	Type	G. M. T. begin. distur.		Groups	Number	Value	Character	
			h	*m*			*cal*				*h*	*m*			*cal*				*h*	*m*			*cal*		
1	0	...	..	..	...	...	......	...	0	...	..	..	18	370	1.936	*f*	0	...	..	..	17	165	......	...	1
2	0	...	..	..	...	...	......	...	0	...	..	..	...	...	1.930	*f*	1	*i*	13	20	13	95	1.922	*u*	2
3	1	...	..	..	...	...	......	...	2	*i*	23	05	21	160	1.930	*f*	0	...	..	..	9	40	1.931	*f*	3
4	0	...	..	..	8	45	......	...	2	*i*	..	..	17	145	1.934	*f*	0	...	..	..	7	50	1.934	*f*	4
5	0	...	..	..	...	...	......	...	1	*i*	..	..	...	...	1.926	*f*	1	*i*	23	00	6	50	......	...	5
6	0	...	..	..	...	...	......	...	1	*i*	..	..	...	...	1.936	*f*	1	*i*	..	..	5	45	......	...	6
7	0	...	..	..	...	...	......	...	0	...	..	..	8	50	1.945	*f*	0	...	..	..	11	75	......	...	7
8	1	*p*	19	20	...	...	......	...	0	...	..	..	10	75	1.939	*f*	0	...	..	..	10	90	......	...	8
9	1	*p*	..	..	9	65	......	...	0	...	..	..	8	60	1.935	*f*	0	...	..	..	10	90	......	...	9
10	1	...	..	..	11	90	......	...	1	*i*	..	..	10	80	......	...	0	...	..	..	9	75	......	...	10
11	1	*i*	..	..	9	70	......	...	1	*i*	..	..	...	...	1.940	*f*	0	...	..	..	...	...	1.931	*f*	11
12	0	...	..	..	...	...	......	...	0	...	..	..	...	...	1.945	*f*	0	...	..	..	...	...	1.926	*f*	12
13	1	*i*	14	00	...	...	......	...	0	...	..	..	...	...	1.944	*f*	0	...	..	..	...	...	1.923	*f*	13
14	0	...	..	..	...	...	......	...	0	...	..	..	...	...	......	...	1	*i*	16	00	6	30	1.928	*f*	14
15	0	...	..	..	9	85	......	...	0	*b*	3	25	8	90	......	...	1	*i*	0	55	...	...	......	...	15
16	0	...	..	..	...	...	......	...	1	...	..	..	9	85	......	...	1	*i*	..	..	...	...	......	...	16
17	0	...	..	..	11	80	......	...	0	...	..	..	9	85	......	...	0	...	..	..	...	...	......	...	17
18	0	...	..	..	10	90	......	...	0	...	..	..	8	140	......	...	0	...	..	..	...	...	......	...	18
19	0	...	..	..	9	80	1.934	*u*	1	*i*	19	05	6	90	1.932	*f*	0	...	..	..	8*	45	......	...	19
20	0	...	..	..	9	90	......	...	1	*i*	..	..	8	130	......	...	0	...	..	..	8	30	......	...	20
21	0	...	..	..	9	70	1.941	*f*	0	...	..	..	9	180	......	...	0	...	..	..	7	40	......	...	21
22	0	...	..	..	12	155	......	...	0	...	..	..	10	145	1.947	*f*	1	*i*	17	00	...	...	......	...	22
23	0	...	..	..	10	120	......	...	0	...	..	..	13	220	......	...	1	*i*	..	..	12	60	......	...	23
24	0	...	..	..	...	...	......	...	0	*b*	8	50	12	200	1.940	*s*	0	...	..	..	...	...	......	...	24
25	0	...	..	..	13*	140	......	...	0	...	..	..	...	...	1.940	*f*	0	...	..	..	10	65	......	...	25
26	0	...	..	..	13*	185	......	...	0	...	..	..	12	165	1.933	*f*	0	...	..	..	...	...	......	...	26
27	1	*p*	..	..	17*	220	......	...	0	...	..	..	16	180	1.934	*f*	1	*i*	20	56	7	110	......	...	27
28	1	*i*	..	..	...	...	......	...	0	...	..	..	19	170	......	...	1	*i*	..	..	8	75	......	...	28
29	0	...	..	..	...	...	1.927	*f*									0	...	..	..	11	70	......	...	29
30	0	...	..	..	...	...	1.928	*f*									0	...	4	00	13	95	......	...	30
31	1	*p*	15	12*	...	...	1.943	*f*									2	...	3	20	13	125	......	...	31
Mean	0.3	...	..	..	11	106	1.935	...	0.4	...	..	..	12	141	1.937	...	0.4	...	..	..	10	72	1.928	...	Mean

*Revision of value originally broadcast.

Greenwich mean time for ending of storms: 1^h, January 9; $13^h 05^m$, January 14; $0^h 24^m$, February 1; 4^h February 4; 3^h, March 6; 7^h, March 15; $2^h 30^m$, March 16; 11^h, March 28; 0^h, April 1.

Kennelly-Heaviside Layer heights, Washington, D. C., January to March, 1937
(Nearest hour, Greenwich mean time, of all observations is 17)

Date	Freq.	Ht.	Date	Freq.	Ht.	Date	Freq.	Ht.	Date	Freq.	Ht.
1937	*kc/sec*	*km*	*1937*	*kc/sec*	*km*	*1937*	*kc/sec*	*km*	*1937*	*kc/sec*	*km*
Jan. 6	2,500	130	Jan. 27	11,200	410	Feb. 17	12,800	400	Mar. 17	2,500	110
" "	3,350	160	" "	11,200	530	" "	12,800	510	" "	3,850	110
" "	3,380	330	" "	11,800	500	" "	13,600	480	" "	3,850	240
" "	3,700	240	" "	12,000	600	" "	13,800	*	" "	4,000	230
" "	4,400	250	" "	12,200	*	" 24	2,500	130	" "	4,400	250
" "	6,200	260	Feb. 5	2,500	130	" "	3,700	150	" "	5,000	280
" "	9,400	300	" "	3,500	160	" "	3,850	*	" "	6,200	270
" "	10,600	310	" "	3,600	190	" "	3,900	270	" "	7,800	280
" "	10,600	370	" "	3,650	260	" "	4,400	240	" "	11,000	380
" "	11,200	330	" "	4,000	240	" "	6,200	280	" "	11,000	440
" "	11,200	430	" "	7,000	260	" "	8,600	320	" "	11,600	400
" "	12,000	460	" "	10,200	300	" "	11,000	330	" "	11,600	530
" "	12,200	*	" "	11,400	320	" "	11,000	350	" "	12,200	440
" 13	2,500	130	" "	11,400	360	" "	13,200	380	" "	12,400	*
" "	3,280	160	" "	12,600	370	" "	13,200	420	" 24	2,500	120
" "	3,300	290	" "	12,600	410	" "	13,600	400	" "	3,400	140
" "	3,550	230	" "	13,200	390	" "	13,600	480	" "	3,800	*
" "	4,400	250	" "	13,200	560	" "	14,400	500	" "	3,870	260
" "	6,200	260	" "	13,600	*	" "	14,600	*	" "	4,100	220
" "	10,200	300	" 10	2,500	130	Mar. 3	2,500	120	" "	4,400	230
" "	10 800	320	" "	3,300	140	" "	3,700	170	" "	4,800	260
" "	10,800	370	" "	3,470	230	" "	3,800	*	" "	6,200	280
" "	11,200	320	" "	3,550	170	" "	3,940	290	" "	9,400	330
" "	11,200	460	" "	3,570	280	" "	4,400	240	" "	11,400	370
" "	11,800	410	" "	4,000	230	" "	6,200	260	" "	11,400	410
" "	12,000	*	" "	4,400	250	" "	8,600	280	" "	12,200	390
" 20	2,500	120	" "	6,200	260	" "	11,000	320	" "	12,200	530
" "	3,440	160	" "	9,000	270	" "	13,000	370	" "	13,000	530
" "	3,480	*	" "	11,000	290	" "	13,000	500	" "	13,200	*
" "	3,510	260	" "	12,000	320	" "	13,600	440	" 31	2,500	120
" "	3,800	230	" "	12,000	350	" "	13,800	*	" "	3,500	150
" "	4,400	250	" "	13,200	350	" 10	2,500	120	" "	3,770	180
" "	6,200	270	" "	13,200	410	" "	3,400	140	" "	3,800	*
" "	7,800	290	" "	14,000	400	" "	3,600	*	" "	3,850	240
" "	9,400	330	" "	14,400	480	" "	3,840	240	" "	4,000	230
" "	10,400	370	" "	14,600	*	" "	4,000	220	" "	4,400	260
" "	10,800	450	" 17	2,500	130	" "	4,400	230	" "	5,200	350
" "	11,000	490	" "	3,720	140	" "	6,200	260	" "	5,600	400
" "	11,200	*	" "	3,800	*	" "	8,600	300	" "	5,700	410
" 27	2,500	130	" "	3,920	250	" "	10,200	320	" "	6,200	410
" "	3,600	150	" "	4,400	260	" "	12,000	360	" "	7,000	400
" "	3,700	*	"	6,200	270	" "	12,000	420	" "	8,000	430
" "	3,800	300	" "	8,600	300	" "	12,600	370	" "	8,000	500
" "	4,400	250	" "	10,200	320	" "	12,600	500	" "	8,600	480
" "	6,200	280	" "	12,000	350	" "	13,400	470	" "	8,600	730
" "	9,400	340	" "	12,000	410	" "	13,600	*	" "	9,400	700

* = No value obtained.
Errata—In table of KHL-heights, p. 90 of this Journal for March 1937, note following revisions: October 14, items 12 and 13, change 14,000 to 11,400; November 11, item 14, change 14,000 to 14,800.

spots. It is to be noted that sunspot-numbers such as those from Zürich can be obtained from the number of groups and spots given in the Table by the formula $N=k\ (10g+s)$, where the mean value of k for Mount Wilson was 0.53 during 1936.

Mount Wilson Observatory is now supplying corrections and additions to the sunspot-data which are broadcast in the *URSI*gram. So far as possible, these additional and corrected values will be used in this

tabular summary and will be designated as such in footnotes to the Table.

Beginning January 1, 1934, the magnetic information of the *URSI*-gram is for Cheltenham, Maryland, instead of Tucson, Arizona. In addition to this change in observatory, the data cover the 24 hours ending 8 A. M., 75° west meridian mean time, instead of the 24 hours ending at 7 A. M., 105° west meridian mean time.

The columns headed solar constant show (1) the value in calories of the solar constant, and (2) by letters *s*, *f*, and *u* whether the determination was satisfactory, fair, or unsatisfactory, respectively.

In accordance with information received from Dr. C. G. Abbot, Secretary of the Smithsonian Institution, transfer from Table Mountain to Montezuma solar-constant values was made as of October 23, 1934. Table Mountain for a considerable time has been 0.012 calorie above Montezuma, and above the scale of 1913 to 1930. Hence the value of October 23, 1934, and succeeding values are on a scale 0.012 calorie lower than previous ones.

Dr. Abbott announced on March 6, 1937, "solar-constant values discontinued owing to important change in methods."

The data for the table of Kennelly-Heaviside Layer heights which is self-explanatory are supplied by the National Bureau of Standards.

DEPARTMENT OF TERRESTRIAL MAGNETISM,
CARNEGIE INSTITUTION OF WASHINGTON,
Washington, D. C.

C. C. ENNIS

PROVISIONAL SOLAR AND MAGNETIC CHARACTER-FIGURES, MOUNT WILSON OBSERVATORY, JANUARY, FEBRUARY, AND MARCH, 1937

Greenwich mean time							Range hor. int.
Beginning			Ending				
1937	*h*	*m*	*d*	*h*	*m*		γ
Jan. 27	8	38	27	24	..		136
Feb. 2	23	02	4	02	..		174
Mar. 1	8	..	2	22	..		99
Mar. 5	4	..	5	23	..		86
Mar. 26	20	56	28	10	..		94
Mar. 31	3	17	31	24	..		168

On January 27 from $19^h\,04^m$ to $19^h\,45^m$, the magnetometer recorded a disturbance in the Earth's magnetic field, which occurred simultaneously with a complete fade-out in short-wave radio transmission on the Pacific Coast. *H* first decreased 41 gammas in 11 minutes, recovering 37 gammas in the next 30 minutes. Cloudy weather prevented solar observations at that time, although observations earlier in the day showed considerable activity on the Sun.

The February storm occurred when a very large active sunspot-group was three days past the central meridian. Dr. Hubble reported seeing an aurora during this magnetic storm at 8^h, GMT, February 3. He described the aurora as reddish in color with a few typical streamers.

The storm of March 1 occurred when a very large sunspot was nearing the central meridian, crossing it on March 2.1, 16° north of the center of

Day	January 1937								February 1937								March 1937							
	K_2		$H\alpha B$		$H\alpha D$		No. groups	Mag'c char.	K_2		$H\alpha B$		$H\alpha D$		No. groups	Mag'c char.	K_2		$H\alpha B$		$H\alpha D$		No. groups	Mag'c char
	A	B	A	B	A	B			A	B	A	B	A	B			A	B	A	B	A	B		
1	....	....	....	....	....	....	....	....	5	5	5	4	4	2	18	0.5	4	4	4[d]	4	3	2	17	1
2	....	....	....	....	....	....	....	....	....	....	....	....	....	....	20	0	4	4	4	3	4	2	13[h]	0.5
3	....	....	....	....	....	....	....[f,j]	0.5	5	3	5[dd]	3	4	2	21[g]	1.5	4	3	4[d]	3	4	1	9[b]	0
4	5	4	4	3[c]	2	2	8	0	5	3	5	3	3	2	17	0.5	3	1	3	1	4	1	7[b]	0
5	....	....	....	....	....	....	....[k]	0	....	....	....	....	....	....	....	0.5	3	2	3[d]	2	3	2	6	1
6	....	....	....	....	....	....	....	0	....	....	....	....	....	....	....	0.5	....	....	....	....	....	....	5	0
7	....	....	....	....	....	....	....	0.5	3	2	3	2	2	1	8	0	3	2	3	2	3	2	11	0
8	....	....	....	....	....	....	....	0	4	3	3[d]	3	2	1	10[b]	0	4	3	4	3	3	1	10[g]	0
9	....	....	....	....	....	....	9	0.5	4	4	3	3	3	1	8[b]	0.5	4	3	4	3	3	1	10	0
10	3	2	2	2	3	2	11	1	....	....	....	....	....	....	10[b]	0.5	4	3	4	3	3	3	9	0
11	3	2	3	2	3	3	9	0.5	....	....	....	....	....	....	....	0.5	....	....	....	....	....	....	....	0
12	....	....	....	....	....	....	....	0	....	....	....	....	....	....	....	0	....	....	....	....	....	....	....	0
13	....	....	....	....	....	....	....	0.5	....	....	....	....	....	....	....[h]	0.5	....	....	....	....	....	....	....	0.5
14	....	....	....	....	....	....	....	0	....	....	....	....	....	....	....	0	....	....	....	....	....	....	6	0.5
15	3	4	3	3	3	2	9	0	3	3	....	....	....	....	8	0	....	....	....	....	....	....	....	1
16	....	....	....	....	....	....	....[e]	0	3	2	3	2	3	3	9	0	....	....	....	....	....	....	....	0
17	3	3	3	3	3	3	11	0	3	3	4[d]	3	4	3	9	0	....	....	....	....	....	....	....	0
18	3	3	3	3	4	4	10	0	4	3	4	3	4	4	8	0.5	....	....	....	....	....	....	....	0
19	....	....	....	....	....	....	9	0	4	3	4	3	3	3	6	0.5	3	2	3	2	4	3	8	0
20	....	....	....	....	....	....	9	0	4	3	4[d]	2[c]	4	3	8	0.5	3	1	3	1	4	3	8	0
21	4	4	4	3	4	2	9[b]	0	4	4	4[d]	3[c]	4	3	9[j]	0.5	4	2	4	2	4	3	7	0
22	5	4	4	4	4	3	12[b]	0	5	3	4[d]	3	3	2	10	0	....	....	....	....	....	....	....	1
23	4	4	4	4	4	4	10[i]	0	5	3	5	3[c]	3	1	13[j]	0	4	4	4	3	4	4	12	0
24	....	....	....	....	....	....	....[g]	0	5	4	5	4	3	2	12[i]	0.5	....	....	....	....	....	....	....	....
25	5	4	5	4	3	2	13	0	....	....	....	....	....	....	....	0	....	....	....	....	....	....	10	0.5
26	4	3	4	3	3	1	15[b,i]	0	5	4	5	4	2	1	12	0	....	....	....	....	....	....	....	0.5
27	....	....	....	....	....	....	17	1	5	5	4[d]	4	2	2	16	0	....	....	....	....	....	....	7[i]	1
28	....	....	....	....	....	....	....	0.5	5	4	3	4	3	2	19[h]	0	4	4	4	4	5	5	8	0.5
29	....	....	....	....	....	....	....	0.5									4	4	4	4	4	1	11[h]	0
30	....	....	....	....	....	....	....	0.5									4	3	4	3	4	1	13[a]	0.5
31	....	....	....	....	....	....	....[r,h]	0									4	3	4[d]	3	4	2	13[a,h]	1.5
Mean	3.8	3.4	3.5	3.1	3.3	2.5	10.7	0.2	4.3	3.4	4.1	3.1	3.1	2.1	12.0	0.3	3.7	2.8	3.7	2.7	3.7	2.2	9.5	0.3

NOTE—For an explanation of these tables see this JOURNAL, 35, 47-49 (1930). The character-figures of solar phenomena are estimated from the spectroheliograms which are made with a 2-inch solar image, usually in the early morning. The very bright chromospheric eruptions are reported in these notes if observed at any time during the day.

?Indicates an uncertain value which should be given low weight.

a, b Formation of a new group which later developed to average size or larger; (a) less than 30° from the center of the disc, (b) more than 30° from the center of the disc.

c, d Very bright chromospheric eruptions; (c) less than 30° from the center of the disc, (d) more than 30° from the center of the disc.

the solar disc. Bright chromospheric eruptions were observed on March 1 in two groups approaching the west limb.

At the time of the storm of March 5 the large spot was nearing the west limb. A bright chromospheric eruption was observed in a group near the east limb. Another group, 40° east, was developing rapidly.

No solar observations were possible at Mount Wilson on March 26, but active groups were present on March 25 and 27.

On March 31 a magnetic storm occurred when two groups which were just developing were crossing the central meridian.

CARNEGIE INSTITUTION OF WASHINGTON, MOUNT WILSON OBSERVATORY,
Pasadena, California
SETH B. NICHOLSON
ELIZABETH E. S. MULDERS

THE AURORA OF FEBRUARY 2, 1937

A number of letters have been received at the University of Saskatchewan from persons located approximately in latitude 54° north and longitude 107° west, describing what was undoubtedly a red aurora on the night of February 2, 1937. The color of the aurora was described variously as red, crimson, and blood-red. All reports emphasized the lack of the usual auroral colors. One correspondent, when he saw the display appearing on the horizon, thought that his neighbor's barn was afire and had gone to his assistance. Apparently the display was observed at about $18^h 30^m$, and continued until about 23^h, 105° west meridian time. The display made its appearance on the northwest horizon, and then rose and spread quickly eastward until the whole northern sky was filled with light almost to the zenith. From the description it would appear that arcs, arcs with ray-structure, and glows were the prevailing forms.

UNIVERSITY OF SASKATCHEWAN,
Saskatoon, Canada, March 11, 1937
B. W. CURRIE

THE UNUSUAL AURORA OF MARCH 30, 1937

On the night of March 30, 1937, a remarkable auroral display was visible over a large part of North America.

Dr. E. H. Bramhall, of the University of Alaska, describes the phenomenon as observed by him at College, Alaska, as follows: "The unusual feature of the aurora was the blood-red glow of considerable intensity. At $22^h 45^m$, March 30, 150° west meridian time ($8^h 45^m$ GMT, March 31), I observed such a glow in the area from east to 20° south of east and from the horizon to 20° altitude simultaneously with active rayed bands of unusual color in the same region and in the south and west. In the zenith there remained a partial corona with intense bands towards east and northwest; in fact in all parts of the sky except due north there was evident some activity. At 23^h (9^h GMT, March 31) a similar blood-red glow developed in the south in the region of a very active rayed band. At $23^h 10^m$ ($9^h 10^m$ GMT, March 31) the red was only faintly visible although the activity in all directions was still great."

The extent of the area over which this aurora was visible is indicated by the fact that it was also seen in New England. Mrs. E. D. Waterhouse of Hartford, Maine, writes that the display was of unusual magnificence at that place, the whole sky being illuminated. One of the

most striking features of the display was the light streaming up in the northern sky as "red as fire."

This aurora was accompanied by a strong magnetic storm as indicated on the records of the United States Coast and Geodetic Survey Magnetic Observatory at Cheltenham, Maryland. There was a very marked decrease in vertical intensity (Z) beginning about 0^h, March 31, 75° west meridian time (5^h GMT); this element decreased by about 180 gammas in the course of the next four hours. The seven American operated magnetic observatories reported a mean character-figure of 1.7 for the corresponding half of the Greenwich day, 2.0 being the maximum designation of disturbance.

Department of Terrestrial Magnetism, Carnegie Institution of Washington, *Washington, D. C.* H. D. Harradon

AURORA OF APRIL 25 TO 29, 1937, AT SHAWINIGAN FALLS, CANADA

The following observations were taken in my home town, Shawinigan Falls, which is about half-way between Montreal and Quebec City, Canada.

At the period of the reported magnetic storms, April 25 to April 29, 1937, we were more fortunate than people further south for we could observe the finest display of the Aurora Borealis. It covered half the sky; we could see this light in the east and west as well as in the northern sky, and directly overhead. On one of the nights it extended south to about 20° from the zenith. The light seemed as strong directly overhead as it was towards the north. Looking directly upward, the rays appeared like strong streaks of light falling on us in a shower and slightly bent toward the north. On the night of May 9 I noticed again the same phenomenon and radio reception was rather poor, even from station CKAC, a 5000-watt station 80 miles away which is usually heard clearly.

Shawinigan Falls, May 11, 1937 Leo Germain

AURORA OF APRIL 26 TO 30, 1937, AT ALEXANDRIA BAY, NEW YORK

The aurora was observed at Alexandria Bay, New York (latitude 44° 20′ north, longitude 75° 55′ west) on the nights of April 26, 27, 28, 29, and 30, 1937. The following notes describe the displays on each of these nights.

April 26—A few streamers were visible around $20^h 30^m$, eastern standard time. A faint whitish glow covered the northern sky extending upward about 30°. Occasional rays or streamers appeared.

April 27—At 20^h the entire northern sky was aglow with a greenish yellowish light. No definite formation was at first visible but later patches appeared in different parts of the sky extending to the zenith. These parts had a rapid pulsating movement appearing and disappearing every few seconds. The movement was directed upward from the northern horizon. Later a few rays appeared and streamers extended apparently to great heights, their base seeming to be low in the northern sky. This display continued to a late hour and at times was tinged with intense green when a bundle of rays would start up. The pulsations were very rapid and nearly the whole sky was luminous.

April 28—A glow that covered the entire northern sky with a few streamers appeared about $23^h\ 30^m$. Activity was not as great as on the preceding night.

April 29—A faint greenish glow extended to about 50°. A peculiar narrow patch of light of yellowish color continued about an hour. At times a sort of wave-motion was apparent from east to west. All this disappeared about 22^h.

April 30—A few thin pencils or rays of greenish light extended from low in the northern sky to great heights—almost 90°. A faint glow of greenish color which soon died out.

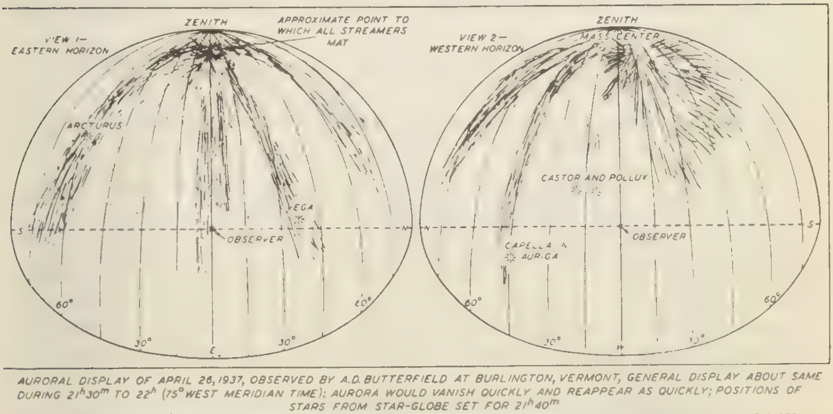
Alexandria Bay, New York DOUGLAS F. MANNING

AURORAL DISPLAY OF APRIL 26, 1937, AT BURLINGTON, VERMONT

The auroral display of April 26, 1937, was first noticed by a former student of mine, A. A. Hutchins, now living at Essex Junction, Vermont. At $22^h\ 10^m$ (75° meridian mean time) he happened to go outside his house and the peculiar appearance of the sky almost actually frightened him. The following is quoted from his description:

"I felt that I was inside a conical tent the top of which was just a little south of the zenith and from all around the horizon in a complete circle there were streamers ascending to the zenith. At first the color was like silvery white, then suddenly changed to a dark red for just a moment, and later to a greenish blue. At times the intensity would diminish a little on one side and then come in with greater intensity."

This peculiar tent-like formation lasted for about 20 minutes, or until $22^h\ 30^m$, and was the most magnificent of the display noted. Mr. Hutchins called me at $22^h\ 30^m$ and I immediately went outdoors and viewed the sky. To me it appeared as if the zenith was filled with a silvery light almost like a mist effect. The zenith was completely covered although the whole horizon was not completely circled as inside a tent. There were



AURORAL DISPLAY OF APRIL 26, 1937, OBSERVED BY A.D. BUTTERFIELD AT BURLINGTON, VERMONT, GENERAL DISPLAY ABOUT SAME DURING $21^h 30^m$ TO 22^h (75° WEST MERIDIAN TIME); AURORA WOULD VANISH QUICKLY AND REAPPEAR AS QUICKLY; POSITIONS OF STARS FROM STAR-GLOBE SET FOR $21^h 40^m$

[VIEW 1 ABOUT $21^h 30^m$ TO $21^h 40^m$ WITH GREAT MASS 5° FROM ZENITH AND STREAM MASSES IN ALL DIRECTIONS WITH PULSATIONS LIKE FLEECY CLOUDS THROUGH WHICH STARS WERE VISIBLE IN BRIGHT MOONLIGHT AND AS MUCH DISPLAY SOUTH OF ZENITH AS NORTH; VIEW 2 ABOUT $21^h 50^m$—DISPLAY LESS GENERAL THAN AT $21^h 40^m$ AND MORE IN EASTERN HALF OF HORIZON—WITH STREAMERS FROM CAPELLA UP SLIGHTLY TINGED WITH RAINBOW COLORS—THE ONLY COLOR NOTED]

streamers all the way around the horizon running to the zenith giving what might be called bands on the inside of a conical tent. I noticed but very little color. Several streamers from the northwest at about 22^h 50^m were slightly tinged with rainbow colors.

On the whole it seemed to me that the display was more of a mass display rather than streamers. First it would instantly clear and then all at once it would be filled with the silvery light as though it was sprayed in. I observed the display for about 30 minutes. The two sketches (views 1 and 2) show the most intense streamers and the position of the mass of light in the zenith. The point at which all of them seemed to center would be about 5° south of the zenith. I checked these general locations up later in the evening from my celestial star globe.

Observations of the magnetic declination made at Burlington, Vermont, on April 29 and May 1, 1937 show little change, if any, from observations made January 1, 1937. They were made with surveyor's transit University of Vermont No. 11 (Old Gurley 10-inch Instrument) taking three sets of six repetitions each. The mean values determined were: January 1, 1937—$10^h.5$, $10^h.8$, and $11^h.0$, 15° 16′.9; April 29, 1937—$11^h.5$, $18^h.2$, and $18^h.5$, 15° 15′.2; May 1, 1937—$11^h.8$, $12^h.1$, and $12^h.3$, 15° 18′.5.

UNIVERSITY OF VERMONT, ARTHUR D. BUTTERFIELD
Burlington, Vermont, May 14, 1937

SUGGESTED MAGNETIC NOMENCLATURE

The introduction of the concept and the term "isopor"[1] has so greatly increased the interest in studies of the secular variation of the geomagnetic elements that the time seems ripe to expand this concept. Therefore, I venture to propose designating the isopor of D, I, H, Z, etc., by "isallogons," "isalloclins," "isallodynams," or specially "isallo-H-dynams," "isallo-Z-dynams," etc.

Perhaps it would be still more expedient to adopt a general name of "E'_t -isoline" for isolines of annual variation E'_t of a geomagnetic element E or of gradients E'_ϕ, E'_λ, E'_h along the latitude ϕ, the longitude λ, and the height h above sea-level.

CENTRAL GEOPHYSICAL OBSERVATORY, BORIS WEINBERG
Leningrad, U.S.S.R., April 23, 1937

INTERNATIONAL CATALOGUE OF MAGNETIC DETERMINATIONS

Having received no reply to my proposal regarding the publication of the international catalogue of magnetic determinations (Union Géod. Géophys. Internat., Ass. Mag. Electr. Terr., Bull. No. 9, 260-263, 1934), it was decided to collect and summarize, if possible, all the results of magnetic determinations accessible to us. On the assumption that the magnetic charts from the middle of the last century furnish a trustworthy representation of contemporary observations, we have not collected determinations subsequent to 1825. We have utilized the following sources:

(1) C. Hansteen, Untersuchungen über den Magnetismus der Erde, Christiania, 1819.

[1]H. W. Fisk, Trans. Amer. Geophys. Union, 10th annual meeting, 215-223 (1930).

(2) W. van Bemmelen, Observations made at the Royal Magnetical and Meteorological Observatory at Batavia, Supplement to v. 21, 1899.
(3) B. P. Weinberg, Catalogue of magnetic determinations made in the U. S. S. R. and in adjacent countries from 1556 to 1931, Leningrad, I, 1929; II, 1932; III, 1933.
(4) B. P. Weinberg, Catalogue of magnetic determinations in polar regions, Moscow, Sect. I and II, 1933 (Sections III to X prepared for printing in 1934).
(5) B. P. Weinberg, First magnetic survey and first magnetic catalogue on world-wide scale (prepared for printing in 1937).
(6) B. P. Weinberg, First catalogues of magnetic determinations at sea, Trans. Central Geophys. Observatory, **16**, 1937 (in press).
(7) E. Sabine, Phil. Trans. R. Soc., **162**, 1873.
(8) L. A. Bauer, United States magnetic declination tables, Washington, 1907.
(9) Morlet, Mém. pres. par div. sav., **13**, 1832.
(10) A von Humboldt, Ann. Phys., **15**, 1829.
(11) Hudson's voyages—Purchas, His pilgrims, London, 1625.
(12) Hjorter, Stockholm, Vet.-Ak. Handl., **8**, 1747.
(13) Schulten, Stockholm, Vet.-Ak. Handl., **20**, 1799.
(14) Hansteen and Due, Resultate magnetischer, astronomischer, und meteorologischer Beobachtungen auf einer Reise nach dem östlichen Sibirien in den Jahren 1828-1830, Christiania, 1863.
(15) C. A. Schott, U. S. Coast Geod. Surv., Rep. for 1882, App. No. 13.
(16) C. A. Schott, U. S. Coast Geod. Surv., Rep. for 1888, App. No. 17.
(17) C. A. Schott, U. S. Coast Geod. Surv., Rep. for 1895, App. No. 1.
(18) J. P. Ault and W. F. Wallis, Terr. Mag., **18**, 126-132 (1913).
(19) W. Dziewulski, Bull. Obs. Astr., Wilno, **2**, 3 (1924).

This brings the number of determinations of D summarized in our universal catalogue to 15,885.

In order to condense this summary without affecting the usability of the data to be published we decided to take the algebraic mean values of epoch t, latitude ϕ, longitude λ, declination D, and later inclination I or horizontal intensity H for all the observations for which t, ϕ, and λ lie within limits as follows.

$$(t_0-25)<t\leq(t_0+25),\ t_0=50r_t$$
$$(\phi_0-\ 5)<\phi\leq(\phi_0+\ 5),\ \phi_0=10r_\phi$$
$$(\lambda_0-\ 5)<\lambda\leq(\lambda_0+\ 5),\ \lambda_0=10r_\lambda$$

where r_t, r_ϕ, and r_λ are whole numbers.

By comparing in various ways the computed mean values $\bar{t}$, $\bar{\phi}$, $\bar{\lambda}$, and $\bar{D}$, we have succeeded, in the great majority of cases, in obtaining sufficiently reliable data for the annual variation D'_t and the gradients D'_ϕ and D'_λ along the meridians and the parallels for equidistant epochs and for equidistant (in angular measure) points. By means of these values of D'_t, D'_ϕ, and D'_λ, we have reduced the values $D_{\bar{t},\bar{\phi},\bar{\lambda}}$ to D_{t_0,ϕ_0,λ_0} thus obtaining from 15,435 separate values of D, 1338 values of $D_{\bar{t},\bar{\phi},\bar{\lambda}}$ and the same number of D_{t_0,ϕ_0,λ_0}. Adding to these the values of $D_{1858,\phi_0,\lambda_0}$ taken from the chart of Neumayer's Atlas des Erdmagnetismus, Leipzig, 1885, and of $D_{1931,\phi_0,\lambda_0}$ taken from the maps of the Deutsche Seewarte and of M[lle] Homery (C.-R. Acad sci., **196**, 787-799, 1933), we obtained 577 diagrams of secular variation of D which may be considered as a nearly unretouched representation of almost all the observations of magnetic declination from 1492 up to the present decade.

The mean values $D_{\bar{t},\bar{\phi},\bar{\lambda}}$ usually lie on unexpectedly smooth lines, a deflection of 1° to 2° being unusual and clearly noted. Unfortunately these deflections in some cases correspond to the values $D_{1858,\phi_0,\lambda_0}$

necessitating a revision of the summarization of the data relating to the period 1826-75 and also—desideratum maximum maximorum—for the period 1876-1915 = epoch 1890, for 1916-25 = epoch 1920, for 1926-35 = epoch 1930, the shortening of the intervals of time between these epochs depending upon the intensive increase of the number of magnetic determinations during the last decades. As an example, there is given in Table 1 an extract from our condensed catalogue of the determinations of D up to 1826 and the corresponding diagram of its secular variations (Fig. 1) for the point $\phi = 20°$ south, $\lambda = 70°$ east.

TABLE 1

$\bar{t}$	$\bar{\phi}$		$\bar{\lambda}$		$\bar{D}$		D'_t	D'_ϕ	D'_λ	$D_\circ$		n	
	°	′	°	′	°	′		′	′	°	′		
1600	−21	33	70	55	−22	31	+3	+2.2	+2.2	−22	23	18_2	6_5
1666	−22	08	71	12	−18	14	+4	+0.3	+0.4	−19	09	5_2	
1703	−21	08	70	25	−13	35	+5	+0.5	+0.5	−13	30	14_1	15_2
1759	−22	14	70	35	− 9	02	+3	+0.6	+0.3	− 8	19	11_1	2_2
1795	−21	22	70	24	− 8	11	+2	+0.5	+0.2	− 7	25	17_1	

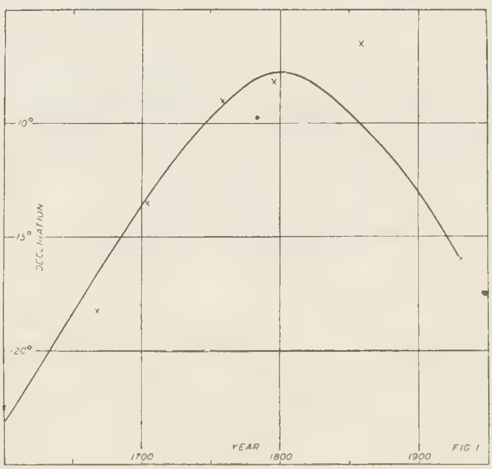


FIG 1

The column n contains the numbers of determinations summarized in the first columns subdivided in groups. These groups relate to different sources from which these determinations have been taken and are indicated by corresponding subscripts referring to the list of sources given above.

Since this list of sources is not exhaustive we shall defer the final preparation of the manuscript for printing until the end of 1937. We accordingly request our magnetician-colleagues to complete this condensed catalogue by sending to me bibliographic information regarding

omitted sources (or by sending copies of the latter). It is hoped that there may be included in the corresponding subdivisions of the catalogue, the lines corresponding to the mean epoch 1850 (and perhaps also to subsequent mean epochs) if our colleagues will kindly send me the $\bar{t}$, $\bar{\phi}$, $\bar{\lambda}$, D (or Σt, $\Sigma\phi$, $\Sigma\lambda$, ΣD) and n summarizing the data of separate investigations pertaining to the magnetic surveys of their countries. Thus our tentative effort will be converted into an international cooperative work of summarization of the whole mass of existing magnetic determinations covering the whole globe.

CENTRAL GEOPHYSICAL OBSERVATORY,
Leningrad, U.S.S.R.

BORIS WEINBERG

OBSERVATIONS AT SECULAR-VARIATION STATIONS IN MEXICO DURING 1936

During November and December 1936, R. O. Sandoval of the Magnetic Section of the National Astronomical Observatory of Mexico made observations of the absolute values of the magnetic elements at Mérida, Campeche, and Veracruz. The results of these observations are shown in Table 1. Mr. Sandoval's instrument was C.I.W.-type magnetometer-inductor No. 107 manufactured by the Precise Instrument Company, and the values shown in the Table are corrected to International Magnetic Standards.

TABLE 1—*Magnetic elements at secular-variation stations in Mexico*

Station	Latitude, north	Longitude, west	Altitude	Date	LMT	Declination east	LMT	Inclination north	LMT	Horizontal intensity
	° ′	° ′	*meters*	1936	*h m*	° ′	*h m*	° ′	*h m*	γ
lérida	20 57.4	89 40.4	9	Nov. 30	12 01	7 10.4	15 14	51 34.9	12 59	29442
				Nov. 30	13 22	7 06.4	....	....	....	.....
				Nov. 30	14 40	7 07.4	....	....	....	.....
				Dec. 1	9 20	7 15.1	11 29	51 34.6	10 00	29518
				Dec. 1	10 40	7 12.6	....	....	....	.....
				Dec. 2	....	....	....	....	9 10-15 29[a]	29461
				Dec. 3*	....	....	9 26-16 25[a]	51 36.3	....	.....
				Dec. 4	8 39-16 41[a]	7 12.1	....	....	....	.....
ampeche	19 50.0	90 32.0	5	Dec. 8	15 41	7 48.4	11 01	49 55.1	10 05	30024
				Dec. 9	11 32	7 50.9	11 04	50 10.4	12 09	29949
				Dec. 9	13 21	7 47.4	....	....	....	.....
				Dec. 9	15 08	7 46.6	....	....	....	.....
eracruz	19 12.6	96 08.3	1	Dec. 20	7 00	8 57.4	9 26	47 36.4	7 30	30788
				Dec. 20	8 08	8 58.1	....	....	....	.....
				Dec. 21	7 10	8 59.1	8 52	47 33.6	7 40	30735
				Dec. 21	8 18	8 59.6	....	....	....	.....

[a]Diurnal-variation series. *Wind too high for earlier observation on this day.

The station at Mérida was at the airport 6.5 km southwest of the City, while at Campeche the station was also at the airport 1.5 km south of the Cathedral. At both of these stations observations could be made only at certain times of the day. At each station a small cement platform was constructed at ground-level, the precise point being marked by a cross. An iron pole 800 meters to the north of each station marks the astronomical meridian. The station at Veracruz was 1.5 km north of the Plaza and without interference from buildings or ships.

OBSERVATORIO ASTRONOMICO NACIONAL, JOAQUÍN GALLO, *Director*
Tacubaya, D. F., Mexico, January 22, 1937

PRINCIPAL MAGNETIC STORMS

Sitka Magnetic Observatory

January to March, 1937[1]

(Latitude 57° 03′.0 N., longitude 135° 20′.1 or $9^h\ 01^m.3$ W. of Gr.)

February 2-4—A disturbance beginning sharply at $23^h\ 04^m$ GMT, February 2, continued with small but gradually increasing amplitudes for a number of hours, reaching its maximum intensity a few minutes after 07^h February 3. At this time the horizontal intensity, which had increased approximately 400 gammas since the beginning of the disturbance, rapidly decreased about 750 gammas, returning in about a half-hour to a little above its normal value. The other two elements took similar, though smaller, excursions at the same time, the vertical intensity decreasing and east declination increasing. Within a few hours the oscillations had nearly died out, but became more violent again from about 16^h to 22^h. Thereafter the storm gradually died away, ending at about 01^h, February 4.

March 5—A storm of moderate severity began about 10^h GMT, March 5. Rapid fluctuations continued until about 15^h, after which the storm gradually died away.

March 15—After several hours of moderate disturbance, a severe storm began about 10^h GMT, March 15. For about five hours the violence of the fluctuations was so great that it is very difficult to trace the different elements. At one time east declination increased more than 2°, the trace going off the sheet on the side for which no reserve-spot is provided. Horizontal intensity decreased more than 800 gammas below its normal value. The violent fluctuations ceased about 15^h, and about two hours later the storm had ended.

March 26-28—This storm had a sharp beginning at $20^h\ 56^m$ GMT, March 26, but showed only slight activity until about 09^h, March 27. Then moderately severe fluctuations began, lasting for about seven hours. This was followed by relative calm, with only occasional bays, until the storm ended about 11^h, March 28.

March 31—A sharp beginning at $03^h\ 17^m$ GMT, March 31, was followed by nearly two hours of only slight activity. At about 05^h large fluctuations began, lasting for five hours. The outstanding feature of this storm was an increase of about 470 gammas in horizontal intensity during the first few hours, followed by a decrease of more than 800 gammas. After 10^h minor fluctuations continued until about 24^h.

John Hershberger, *Observer-in-Charge*

[1]Communicated by R. S. Patton, Director, United States Coast and Geodetic Survey.

Cheltenham Magnetic Observatory

January to March, 1937[1]

(Latitude 38° 44′.0 N., longitude 76° 50′.5 or $5^h\ 07^m.4$ W. of Gr.)

January 27-28—A sudden commencement of a disturbance began at $08^h\ 38^m$ GMT, January 27, after a very quiet period. The disturbance lasted about 20 hours and was characterized by short-period perturba-

[1]Communicated by R. S. Patton, Director, United States Coast and Geodetic Survey.

tions of small amplitude. At the beginning of the disturbance the horizontal intensity decreased 4 gammas, followed by an abrupt increase of 40 gammas. The changes in declination and vertical intensity were small but noticeable.

February 2-3—A storm began abruptly at $23^h\ 05^m$ GMT, February 2. At that time the horizontal intensity decreased 10 gammas in the first minute, then increased 39 gammas during the second minute. The vertical intensity decreased 4 gammas in one minute and the declination increased westward 2′. The perturbations were irregular. A marked increase in vertical intensity lasting about two hours occurred at $01^h\ 30^m$, February 3, when that element increased 62 gammas in a half-hour and remained at the higher value until about $03^h\ 30^m$ when it decreased 75 gammas in four hours. A peak occurred in all three elements beginning about 19^h, February 3, and lasting about 45 minutes. The storm ended about midnight February 3, although the elements were moderately disturbed for the next three days. The ranges were: Declination, 26′; horizontal intensity, 201 gammas; and vertical intensity, 90 gammas.

February 18-19—A sudden commencement of a disturbance began at 19^h 05 GMT, February 18, when the horizontal intensity decreased abruptly 9 gammas and then increased 47 gammas in three minutes. The declination and vertical intensity changed by small amounts. The disturbance following was in general not severe and the average value of the elements remained about normal. The most disturbed part of the storm occurred between 15^h and 20^h, February 19, when the horizontal intensity decreased about 100 gammas in two hours followed by an increase of the same amount in one hour The storm had a very gradual ending.

March 5-6—A disturbance of moderate intensity began abruptly at $07^h\ 27^m$ GMT, March 5, when the horizontal intensity increased 35 gammas in two minutes. The changes in declination and vertical intensity at the beginning were small. The disturbance was characterized by short-period oscillations and lasted until 03^h, March 6. The vertical intensity reached a minimum at 11^h, March 5, and the horizontal intensity reached a minimum at $13^h\ 54^m$, March 5. After reaching its minimum value the horizontal intensity increased 150 gammas in thirty minutes. The ranges were: Declination, 23′; horizontal intensity, 162 gammas; and vertical intensity, 75 gammas.

March 13-14—The Earth's field was moderately disturbed for a few hours from 21^h GMT, March 13, to 05^h, March 14. The most striking feature was the large range in vertical intensity in comparison with the ranges of declination and horizontal intensity. The vertical intensity increased 95 gammas in three hours beginning at 21^h, March 13.

March 15-16—A disturbance began at $00^h\ 55^m$ GMT, March 15, with a bay lasting about thirty minutes. The disturbance was quite mild until $09^h\ 43^m$ when it suddenly became more active in all three elements. It ended at $02^h\ 30^m$, March 16.

March 21-23—A disturbance of moderate intensity began gradually at 17^h GMT, March 21, and continued until 06^h, March 23. The perturbations were irregular in period, but during the more disturbed part from 10^h to 23^h, March 22, the periods were short.

March 26-28—A sudden commencement of a disturbance occurred at

$20^h\ 56^m$ GMT, March 26. The horizontal intensity decreased abruptly 14 gammas, then increased 56 gammas in three minutes. The changes in declination and vertical intensity were small. The perturbations in all three elements were irregular and of not very great range. The activity continued until 11^h, March 28.

March 31-April 1—A storm began at $03^h\ 18^m$ GMT, March 31, with an abrupt increase in horizontal intensity of 35 gammas. The horizontal intensity then decreased 214 gammas in four hours followed by an increase of 63 gammas in ten minutes. The vertical intensity began to decrease at 05^h and was characterized by two peaks of low values at 07^h and 09^h. The declination was irregularly disturbed for the duration of the storm which ended at 03^h, April 1. The ranges were: Declination, 32′; horizontal intensity, 214 gammas; and vertical intensity, 243 gammas.

Albert K. Ludy, *Observer-in-Charge*

Tucson Magnetic Observatory

January to March, 1937[1]

(*Latitude 32° 14′.8 N., longitude 110° 50′.1 or $7^h\ 23^m.3$ W. of Gr.*)

February 2-4—A severe disturbance, beginning with sudden commencements in all three elements at 23^h 04 GMT, February 2, was characterized by short- and moderate-period activity, particularly in D and H, superimposed on two long-period bays. The storm ended at about 02^h GMT, February 4. Ranges were: H, 195 gammas; Z, 46 gammas; D, 16′.

February 18-21—A prolonged interval of very moderate activity, composed principally of short-period fluctuations, particularly in D and H, began with sudden commencements in all three elements at $19^h\ 05^m$ GMT, February 18, and ended at about 24^h GMT, February 21. Ranges were: H, 92 gammas; Z, 36 gammas; D, 13′.

March 5—A moderate disturbance began with sudden commencements in all elements at $07^h\ 26^m$ GMT, March 5. H increased 23 gammas in two minutes. The storm was characterized by short-period activity, especially in D and H. During the interval from 18^h to 19^h, H displayed minor activity having periods of two minutes or less. The disturbance ended at 23^h GMT, March 5. Ranges were: H, 87 gammas; Z, 35 gammas; D, 16′.

March 26-27—A moderate storm began with sudden starts in all elements at $20^h\ 56^m$ GMT, March 26, H increasing 28 gammas in four minutes. The storm consisted of several long bays with superimposed short-period activity, particularly in D and H, occurring for the first five hours following the start and from 08^h to 16^h, March 27. The ending was at about 10^h GMT, March 27. Ranges were: H, 99 gammas; Z, 57 gammas; D, 12′.

March 31-April 1—A brief storm of moderate intensity began at $03^h\ 17^m$ GMT, March 31, with abrupt starts in all elements. H increased 29 gammas in three minutes. The first eight hours were marked by pronounced activity in all elements, especially D and H, with periods ranging from a few minutes to two or three hours. The remainder of the

[1]Communicated by R. S. Patton, Director, United States Coast and Geodetic Survey.

storm consisted of very moderate short-period activity superimposed on a long bay. The ending was at 01^h GMT, April 1. Ranges were: H, 160 gammas; Z, 38 gammas; D, 15′.

J. WALLACE JOYCE, *Observer-in-Charge*

HUANCAYO MAGNETIC OBSERVATORY

JANUARY TO APRIL, 1937

(Latitude 12° 02′.7 S., longitude 75° 20′.4 or 5^h 01^m.4 W. of Gr.)

January 27—A sudden commencement occurred at 03^h 37^m GMT, January 27. In four minutes H increased 28 gammas, Z increased 7 gammas, and D decreased 1′. The records were moderately disturbed from 07^h to 14^h.

January 30—A very marked sudden commencement occurred at 10^h 09^m GMT, January 30. D decreased 1′ and increased 5′ in an interval of four minutes. In the same period, Z increased 9 gammas. A much more marked change occurred in H. A very rapid decrease of 19 gammas was followed by a still sharper increase that moved the H-trace off the record. From 10^h 11^m until 11^h 03^m the H-trace was missing. The value of H during this interval was at least 50 gammas above normal.

February conditions—The month was quiet on the whole, the average character-number being 0.1 on the 0, 1, 2 scale. There was a single "2"-day on February 3. During the month there occurred four sudden commencements, two of them being noteworthy. None of these sudden commencements occurred during the hours while observing the Sun with the spectrohelioscope.

February 2-3—At 23^h 04^m GMT, February 2, there was a marked sudden commencement in all elements which was followed by a magnetic storm lasting for 23 hours. During this storm the range in H was 515 gammas. The minimum value of H at 20^h 02^m, February 3, was 29403 gammas. The maximum value of H was 29918 gammas, at 16^h 20^m, February 3.

February 18-19—At 19^h 04^m GMT, February 18, there occurred a sudden commencement in all elements, a feature of which was a sharp decrease in H of 10 gammas in one minute followed by an increase of 121 gammas during the next five minutes. The hours following were relatively quiet until 12^h 48^m, February 19, when a decrease of 130 gammas in H occurred during a period of ten minutes. This was followed by disturbed conditions until 19^h.

February 21 and 25—At 03^h 27^m GMT, February 21, and at 11^h 44^m, February 25, sudden commencements of smaller magnitude occurred, both of which were followed by quiet magnetic conditions.

Earth-current conditions—The earth-current lines were highly disturbed at the times of the sudden commencements February 2 and 18 and also at 12^h 48^m GMT, February 19. The earth-current lines were moderately disturbed at the times of the sudden commencements, February 21 and 25.

March conditions—March was slightly more disturbed than the two previous months, the average character-number being 0.3 as compared with 0.1 for January and February. There was a single class "2"-day

on March 5, and six "1"-days. During the month there occurred two sudden commencements.

March 26-27—At 20^h 57^m GMT, March 26, occurred a sudden commencement. *H* decreased 6 gammas and then increased 72 gammas within four minutes. *Z* increased 7 gammas, and *D* increased 1′ during the same interval. The following day was moderately disturbed.

March 31—At 03^h 17^m GMT, March 31, a sudden commencement occurred involving an increase in *H* of 33 gammas in four minutes, accompanied by an increase in *Z* of 6 gammas in the same interval. The *D*-trace was only slightly disturbed. The remaining hours of the day until 20^h were moderately disturbed. Both sudden commencements were accompanied by sharp peaks in the earth-current traces.

Considerable disturbance of the magnetic traces also occurred from 10^h to 22^h GMT, March 5, and from 12^h to 15^h GMT, March 15. On both of these occasions the sky was overcast so that no spectrohelioscope observations were possible.

April conditions—The average character-number for April was the same as for March, namely, 0.3. The end of the month was marked by strong magnetic disturbances. All days from April 1 to 23, inclusive, were "0"-days. Of the last seven days, three were "2"-days, and four were "1"-days.

April 24-28—A magnetic storm, starting with a sudden commencement at 12^h 02^m GMT, April 24, involving an increase in *H* of 65 gammas in two minutes, continued through April 24, 25, 26, 27, and 28. Quieter periods occurred during the forenoons of April 25, 26, and 27. A second sudden commencement occurred at 15^h 46^m, April 25, during which *H* increased 140 gammas in four minutes. Both sudden commencements were reflected in the *D*- and *Z*-traces but to a much less extent than in *H*. A marked feature of this disturbed period was large bays in the *H*-trace, both maxima and minima. The usual depression in the average value of *H* during storms was very marked during the period under discussion. The daily ranges in *H* during the five days April 24 to 28, inclusive, were 526, 578, 644, 371, 263 gammas, respectively. A very low value of *H*, 29275 gammas, occurred April 26. The Sun was not under observation through the Observatory spectrohelioscope at the times of the two sudden commencements. On both occasions simultaneous earth-current disturbances occurred. The spectrohelioscope report showed active flocculi on April 22, 25, and 27. April 23 was cloudy but there was no activity noted on April 24, 26, and 28, although the Sun was clearly visible.

FRANK T. DAVIES, *Observer-in-Charge*

APIA OBSERVATORY

JANUARY TO MARCH, 1937

(Latitude 13° 48′.4 S., longitude 171° 46′.5 or 11^h $27^m.1$ W. of Gr.)

February 2-5—A fairly intense magnetic disturbance commenced suddenly at 23^h 02^m GMT, February 2. The *Z*-trace showed considerable fluctuations during February 3 but unfortunately records of *H* and *D* were not obtained until 20^h, February 3. The *H*- and *D*-traces were

moderately disturbed during February 4 and 5 and gradually returned to normal.

February 9-11—An indefinite disturbance of all three elements occurred February 9, 10, and 11.

February 19-21—All three elements were again somewhat disturbed over the period February 19-21.

March 1-2—The three elements were somewhat disturbed during March 1 and 2.

March 4-6—A disturbance commenced indefinitely late March 4 and lasted through March 5 and 6.

March 13-16—Another slight storm commenced gradually March 13 and lasted until March 16.

March 21—A further slight disturbance began gradually late March 21.

March 26-28—A minor magnetic storm commenced with a sudden rise in H and Z at $20^h\ 54^m$ GMT, March 26, and all three elements were slightly disturbed until March 28.

March 31-April 1—A small sudden rise in H at $03^h\ 15^m$ GMT, March 31, introduced a fairly intense disturbance. H fell rapidly immediately after the commencement, reaching a minimum at $07^h\ 30^m$, March 31.

W. Ralph Dyer, *Acting Director*

Watheroo Magnetic Observatory

January to April, 1937

(Latitude 30° 19′.1 S., longitude 115° 52′.6 or $7^h\ 43^m.5$ E. of Gr.)

January 27—There was a sudden commencement January 27 at $08^h\ 36^m\ 44^s$ GMT, as shown by the record of the Crichton-Mitchell vertical-intensity inductometer. D moved 2′ eastward abruptly and swung back, sharply followed by a second movement of 2′ eastward during the next four minutes of time. H increased 25 gammas in three minutes with a further increase of 5 gammas in the next minute. The numerical value of Z decreased 9 gammas abruptly, followed by a further decrease of 16 gammas in five minutes. This disturbance of short duration had a range in H of 166 gammas, the ranges in D and Z being practically normal.

February 2-4—This storm began with a moderately marked sudden commencement February 2 at $23^h\ 04^m\ 10^s$ GMT. D, after a small initial westerly motion, moved 3′ easterly during the next three minutes of time. H increased 15 gammas in the first minute followed by a further increase at a slower rate. The numerical value of Z increased slightly initially, then decreased 14 gammas by steps during the next three minutes. About an hour and twenty minutes after the sudden commencement, the horizontal intensity began to decrease, reaching the minimum for the storm at about 08^h, February 3. The storm ended at approximately 16^h, February 4. Ranges: Declination, 22′; horizontal intensity, 173 gammas; vertical intensity, 95 gammas.

February 18-20—There was a sudden commencement February 18 at $19^h\ 04^m\ 36^s$ GMT. D, after a small initial westerly motion, moved

4′ easterly in three minutes of time. *H* increased 26 gammas in three minutes. The numerical value of *Z*, after a small initial increase, decreased 13 gammas in three minutes. The value of horizontal intensity remained high until midnight February 18, then dropped off slowly. Moderately disturbed conditions prevailed until 20^h, February 20. Ranges: Declination, 18′; horizontal intensity, 76 gammas; vertical intensity, 139 gammas.

February 21—A sudden commencement occurred February 21 at $03^h\,26^m\,34^s$ GMT. *D*, after a small initial westerly motion, moved 2′ easterly in three minutes of time. *H* increased 17 gammas in six minutes. The numerical value of *Z* decreased 5 gammas abruptly, then increased 8 gammas in three minutes. The elements were slightly disturbed until midnight.

February 24—This sudden commencement began February 24 at $8^h\,11^m\,03^s$ GMT. *D* moved westerly 1′ in one minute and *H* increased 13 gammas, then gradually fell off. Preceding the commencement, the numerical value of *Z* had been increasing with the normal diurnal change but at the sudden commencement *Z* decreased 4 gammas in five minutes, after which it continued its normal increase.

February 25—The elements were slightly disturbed from 06^h to $08^h\,30^m$ GMT, February 25. An abnormally quiet interval followed, broken by a sudden commencement at $11^h\,42^m\,30^s$. *D* moved 1′ easterly then 2′ westerly and then 2′ easterly in a space of eight minutes of time. *H*, after a slight initial decrease, increased 24 gammas in three minutes then fell off 12 gammas in the next five minutes. The numerical value of *Z* decreased 5 gammas, increased 5 gammas, and decreased 5 gammas all in eight minutes. The disturbance was of short duration.

March 13-16—This storm began with a slight disturbance about $16^h\,20^m$ GMT, March 13, increased in intensity from about 08^h, March 15, and faded out to a normal trace about 02^h, March 16. Ranges on March 13, 14, and 15, respectively, were: Declination, 15′, 14′, and 18′; horizontal intensity, 37, 111, 119 gammas; vertical intensity, 108, 87, and 140 gammas.

March 26-28—This disturbance began with a sudden commencement March 26 at $20^h\,56^m\,35^s$ GMT. *D* moved abruptly 1′ westerly and then moved 2′.5 easterly in three minutes of time. *H* increased 15 gammas in three minutes. The numerical value of *Z* increased 2 gammas abruptly and then decreased 13 gammas in about three minutes. The sudden commencement was followed by a disturbance which reached its maximum intensity during the twelfth hour on March 27 and which ended about noon on March 28. Ranges: Horizontal intensity, 102 gammas; vertical intensity, 140 gammas.

March 31—A sudden commencement occurred March 31 at $03^h\,17^m\,20^s$ GMT. *D* moved 3′ westerly in four minutes of time and *H* increased 20 gammas in six minutes. The numerical value of *Z* increased 7 gammas abruptly and then decreased 14 gammas in four minutes. The disturbance which followed was of short duration during which the ranges were: Declination: 16′; horizontal intensity, 80 gammas; vertical intensity, 121 gammas.

April 24-25—A sudden commencement occurred at $12^h\,01^m\,36^s$ GMT, April 24. *D* moved 1′ eastward, then 2′.5 westward in three minutes of time, *H* increased 28 gammas in three minutes, and the numerical value

of Z decreased 5 gammas, then increased 8 gammas in three minutes. Following the sudden commencement the elements were slightly disturbed, then increasingly disturbed until 22^h and returning to normal by 08^h, April 25. Ranges: Declination, 13′; horizontal intensity, 138 gammas; vertical intensity, 107 gammas.

April 25-26—This moderate disturbance began with a sudden commencement at $15^h\ 48^m\ 20^s$ GMT, April 25. D moved westerly slightly, then 2′ easterly in four minutes of time; H increased 39 gammas in three minutes, and the numerical value of Z decreased 19 gammas in three minutes. The disturbance increased, reaching storm-intensity between 19^h and 20^h and remaining severely disturbed during the next six hours. The disturbance then decreased in intensity, reaching moderately quiet conditions about 08^h, April 26. Ranges: Declination, 23′; horizontal intensity, 120 gammas; vertical intensity, 125 gammas.

April 26-30—This storm was ushered in by a sudden commencement of marked intensity at $17^h\ 55^m\ 08^s$ GMT, April 26. D moved 2′.5 westerly, then 8′ easterly in two minutes of time; H increased 49 gammas in two minutes, and the numerical value of Z increased 11 gammas, then decreased 47 gammas in two minutes. The disturbance, of storm-intensity in the beginning, decreased to character "1" soon after 00^h, April 27; and at 08^h, April 27, slight disturbance remained. During this part of the storm ranges were: Declination, 39′; horizontal intensity, 130 gammas; vertical intensity, 223 gammas. Shortly after 08^h, April 27, the intensity of the disturbance increased, reaching character "1" by 19^h and character "2" at 01^h, April 28. Storm-conditions prevailed until 18^h, April 28. Moderately disturbed conditions continued through April 29 and 30. The ranges during the part of the storm on April 27 and 28 were: Declination, 27′; horizontal intensity, 203 gammas; vertical intensity, 184 gammas.

J. W. GREEN, *Observer-in-Charge*

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Terrestrial Magnetism
and
Atmospheric Electricity

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SOLAR ERUPTIONS AND THEIR IONOSPHERIC EFFECTS—A CLASSICAL OBSERVATION AND ITS NEW INTERPRETATION

BY J. BARTELS

The important discovery that bright eruptions in the solar chromosphere cause simultaneous radio fade-outs and distinct terrestrial-magnetic effects has been announced and discussed in the last issues of this JOURNAL[1]. J. A. Fleming,[2] giving an outline of the bearing of this new evidence on theories of the ionosphere and terrestrial-magnetic variations, mentions that Carrington and Young nearly 80 years ago interpreted certain observations as indicating the simultaneity of solar eruptions and magnetic disturbances, but that this opinion was abandoned by other investigators because they looked for it in vain in the great magnetic storms. If the radio fade-outs had not given such strong evidence of ionospheric disturbances simultaneous with solar eruptions, it is not impossible that the comparatively small, though distinct, terrestrial-magnetic effects would still have escaped detection.

This discovery has been made possible by the increase in the program of spectroscopic, ionospheric, and terrestrial-magnetic observations, and by the comparative frequency with which intense fade-outs occur (21 fade-outs in the year 1936, of which at least 13 were accompanied by visible solar eruptions). As the observational material for great magnetic disturbances increases much more slowly, with only a few cases during each sunspot-maximum, we have still to rely on the numerous discussions of the relationship to sunspots, which may be interpreted as evidence for solar corpuscles, traveling about a day from the Sun to the Earth. Because of the rarity mentioned, and not only for historical reasons, it may be of interest to recall here the original records of the classical case which started the controversy.

Photographic recording had been introduced at Kew Observatory in 1857 by Balfour Stewart. We quote from his report "On the great magnetic disturbance which extended from August 28 to September 7, 1859, as recorded by photography at the Kew Observatory,"[3] a storm which is one of the six outstanding storms observed within the last 100 years.

"During the latter part of August, and the beginning of September, 1859, auroral displays of almost unprecedented magnificence were observed very widely throughout our globe, accompanied (as is invariably the case) with excessive disturbances of the

[1]J. H. Dellinger, Terr. Mag., **42**, 49-53 (1937); A. G. McNish, Terr. Mag., **42**, 109-122 (1937); L. V. Berkner and H. W. Wells, Terr. Mag., **42**, 183-194, 301-309 (1937) and earlier papers cited there. See also the notes by H. W. Newton, Nature, **137**, 363 (1936); **138**, 1017 (1936).

[2]Terr. Mag., **41**, 404-406 (1936).

[3]Phil. Trans. R. Soc., 1861. 423-430.

magnetic needle. The interest attached to these appearances is, if possible, enhanced by the fact that at the time of their occurrence a very large spot might have been observed on the disc of our luminary. . . . In not a few instances telegraphic communication was interrupted, owing to the current produced in the wires; and in some cases this proved so powerful that it was used instead of the ordinary current, the batteries being cut off and the wires simply connected with the Earth. . . . We have two distinct well-marked disturbances, each commencing abruptly and ending gradually, . . . on the evening of August 28, and on the early morning ($4^{h}\ 50^{m}$) of September 2. They correspond in time to the two great auroral displays[4]. . . . It is impossible to state with accuracy what were the greatest departures from the mean value, as the curves for all the elements went beyond the sensitive paper; very approximately, however, we may estimate them as follows: 2° 20′ in declination; −0.04 of the whole in horizontal force [about 700γ], 0.01 of the whole in vertical force [about 400γ]."

The records are reproduced from Balfour Stewart's paper in Figure 1 for three days, showing comparatively quiet conditions on August 30 and 31 (after the first storm August 28 and 29—not discussed here) the short disturbance beginning $11^{h}\ 15^{m}$, September 1, and the outbreak of the second great storm at $4^{h}\ 50^{m}$, September 2; time-marks have been inserted as accurately as possible according to the indications given

[4] Seen as near the equator as Havana, Cuba, and on the Sandwich Islands (20° N) early in September.

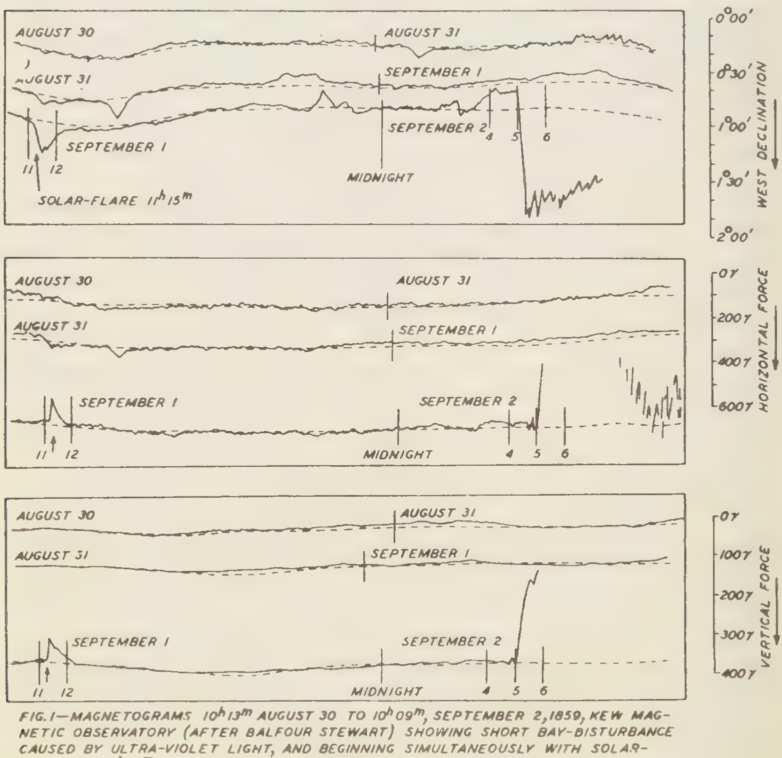

FIG. 1—MAGNETOGRAMS $10^{h}13^{m}$ AUGUST 30 TO $10^{h}09^{m}$, SEPTEMBER 2, 1859, KEW MAGNETIC OBSERVATORY (AFTER BALFOUR STEWART) SHOWING SHORT BAY-DISTURBANCE CAUSED BY ULTRA-VIOLET LIGHT, AND BEGINNING SIMULTANEOUSLY WITH SOLAR-FLARE AT $11^{h}15^{m}$ SEPTEMBER 1, AND BEGINNING, 18 HOURS LATER, OF GREAT MAGNETIC STORM CAUSED BY SOLAR CORPUSCLES

in the paper. The dotted lines representing normal, quiet conditions, were furnished by General Sabine, who assured Balfour Stewart that "this great magnetic storm, for excessive violence of character and length of duration, had never been surpassed by any similar phenomenon which has occurred in his long and varied experience."

We now quote R. C. Carrington's report, and reproduce his drawing (Fig. 2) showing the large spot in heliographic latitude 20° north, and near the central meridian.

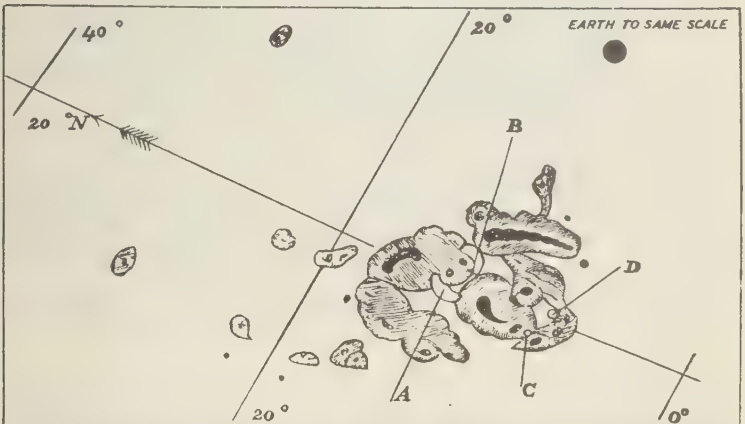

FIG 2—SOLAR SKETCH, SEPTEMBER 1, 1859, BY R.C. CARRINGTON (AFTER BALFOUR STEWART)

"While engaged in the forenoon of Thursday, September 1, 1859, in taking my customary observation of the forms and positions of the solar spots, an appearance was witnessed which I believe to be exceedingly rare. The image of the Sun's disc was, as usual with me, projected on to a plate of glass coated with distemper of a pale straw color, and at a distance and under a power which presented a picture of about 11 inches in diameter. I had secured diagrams of all the groups and detached spots and was engaged at the time in counting from a chronometer and recording the contacts of the spots with the cross-wires used in the observation, when within the area of the great north group (the size of which had previously excited general remark), two patches of intensely bright and white light broke out, in the positions indicated in the appended diagram by the letters *A* and *B*, and of the forms of the spaces left white. My first impression was, that by some chance a ray of light had penetrated a hole in the screen attached to the object-glass, by which the general image is thrown onto shade, for the brilliancy was fully equal to that of direct sunlight; but, by at once interrupting the current observation, and causing the image to move by turning the R. A. handle, I saw I was an unprepared witness of a very different affair. I thereupon noted down the time by the chronometer, and, seeing the outburst to be very rapidly on the increase, and being somewhat flurried by the surprise, I hastily ran to call some one to witness the exhibition with me, and on returning within 60 seconds, was mortified to find that it was already much changed and enfeebled. Very shortly afterwards the last trace was gone; and although I maintained a strict watch for nearly an hour, no recurrence took place. The last traces were at *C* and *D*, the patches having traveled considerably from their first position, and vanishing as two rapidly fading dots of white light. The instant of the first outburst was not 15 seconds different from $11^h\ 18^m$ Greenwich mean time, and $11^h\ 23^m$ was taken for the time of disappearance. In this lapse of five minutes, the two patches of light traversed a space of about 35,000 miles, as may be seen by the diagram, which is given exactly on a scale of 12 inches to the Sun's diameter. On this

scale the section of the Earth will be very nearly equal in area to that of the detached spot situated most to the north in the diagram, and the section of Jupiter would about cover the area of the larger group, without including the outlying portions. It was impossible on first witnessing an appearance so similar to a sudden conflagration, not to expect a considerable result in the way of alteration of the details of the group in which it occurred; and I was certainly surprised, on referring to the sketch which I had carefully and satisfactorily (and I may add fortunately) finished before the occurrence, at finding myself unable to recognize any change whatever as having taken place. The impression left upon me is, that the phenomenon took place at an elevation considerably above the general surface of the Sun, and, accordingly, altogether above and over the great group in which it was seen projected. Both in figure and position the patches of light seemed entirely independent of the configuration of the great spot, and of its parts, whether nucleus or umbra. . . .

"It has been very gratifying to me to learn that our friend Mr. Hodgson chanced to be observing the Sun at his house at Holloway on the same day, and to hear that he was a witness of what he also considered a very remarkable phenomenon. I have carefully avoided exchanging any information with that gentleman, that any value which the accounts may possess may be increased by their entire independence."

Balfour Stewart, after the quotation given, continues:

"On calling at Kew Observatory a day or two afterwards, Mr. Carrington learned that the very moment when he had observed this phenomenon the three magnetic elements at Kew were simultaneously disturbed. If no connection had been known to subsist between these two classes of phenomena, it would, perhaps, be wrong to consider this in any other light than a casual coincidence; but since General Sabine has proved that a relation subsists between magnetic disturbances and sunspots, it is not impossible to suppose that in this case our luminary was taken *in the act*.

"This disturbance occurred as nearly as possible at 11^{h} 15^{m} a. m. Greenwich mean time on September 1, 1859, affecting all the elements simultaneously and commencing quite abruptly."

There can be no doubt that the solar eruption occurred practically simultaneously with the sharp outbreak of the short magnetic disturbance, which is quite distinctly different from an ordinary "bay"; for, while in declination and horizontal intensity some similar movements occur on the preceding days, these were very quiet in vertical intensity. This "precursor of a magnetic storm," as J. de Moidrey might have called it, may perhaps induce a search for similar effects in other storms with sudden commencements, begun by R. L. Faris[5] 27 years ago.

The question, why this striking coincidence has later been discarded as merely fortuitous, is answered in the following characteristic quotation from a paper by W. Ellis "Sunspots and magnetic disturbance."[6]

"Lord Kelvin, in his presidential address to the Royal Society in 1892[7], estimating the amount of work which must be done at the Sun to produce a terrestrial-magnetic storm, considered the result obtained as absolutely conclusive against the supposition that terrestrial-magnetic storms are due to magnetic or other action of the Sun, adding that it seems as if we may be forced to conclude that the supposed connection between magnetic storms and sunspots is unreal, and the seeming agreement between the periods a mere coincidence. But to show that the Sun does not directly produce magnetic disturbance was not to prove that no relation existed, or that the agreement between the periods was accidental. The fact of general relation, however it is to be explained, is so far evident that theory must take account of it. Lord Kelvin, in demonstrating the improbability of the existence of direct connection, may be understood to have had more in mind such a circumstance as the simultaneous observation by Carrington and Hodgson of an outburst on the Sun on 1859 September 1, corresponding in time with a magnetic movement shown on the photographic magnetic records, to which indeed he had referred in an earlier portion of his address. Carrington, one of the observers of the

[5] Terr. Mag., **15**, 209-210 (1910).
[6] Mon. Not. R. Astr. Soc., **61**, 537-541 (1901).
[7] Proc. R. Soc., **52**, 303-308 (1892).

solar movement, while considering the phenomena as deserving of notice, said that 'he would not have it supposed that he even leans towards hastily connecting them.' An occurrence so striking attracted attention, but unfortunately the narrative became repeated with exaggeration of statement, inducing a belief in direct connection. But time at last showed that here was apparently misconception, for although the Sun, in the ordinary routine of solar work, has since been unremittingly watched, and a continuous photographic magnetic record also maintained, similar conditions have not been again observed. The magnetic motion, in the case in question, was in itself in no way remarkable, was indeed slight, and of a character and magnitude such as often occurs, and much greater movements are also sufficiently numerous, but yet direct correspondence has not been made out. The apparent connection, having thus in after years received no further confirmation from observation, was shown also by Lord Kelvin thirty-three years afterwards to be from other considerations improbable. But as before said, the general relation, both with variation of diurnal range and with frequency of magnetic disturbance and storm is undoubted."

Summing up, we may now venture to interpret these classical observations as supporting the new evidence mentioned at the beginning of this paper: The unusually large solar eruption observed by Carrington was accompanied by a simultaneous large magnetic effect lasting less than an hour, presumably caused primarily by a transitory increase of ionization in the ionosphere due to excessive ultra-violet light, and was followed after an interval of $17^h\ 35^m$, by the outbreak of one of the six most violent magnetic storms ever observed, presumably caused primarily by the impact of solar corpuscles.

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MAGNETIC AND ELECTRIC OBSERVATIONS OF THE DRIFT-EXPEDITION TO THE NORTH POLE

By E. K. Fedorov

An important place in the program of work of the Expedition to the North Pole is given to the study of the magnetic and electrical phenomena. Absolute determinations of the magnetic elements will be made with Chasselon theodolite No. 87, adapted for measurements in high latitudes. The declination will be determined by the usual method, and the inclination by the Lamont-method using rods of "dynamo" steel. Two pairs of rods of different sizes will secure a measurement of inclination up to 88°. The horizontal component (H) will be determined by the deflection-method. In order to check the stability of the magnetic moments of the working magnets, oscillations will be effected from time to time. Two of the four magnets taken can be used both for oscillations and deflections and two for deflections only, one of which is of steel and the other is of an alloy of nickel and aluminum. The correspondingly selected magnetic moments of the magnets and the elongated deflection-bars permit measuring the horizontal force up to values of approximately 0.005 CGS. The constants of the apparatus have been determined in the Observatory in Slutzk at a temperature of about $-5°$ C.

Observations of the variations of the magnetic field will be taken by a specially devised portable set of magnetometers with visual readings by the mirror-and-scale method. The distance between the mirror of the magnet and the focal plane of the eye-reading telescope is about 25 cm. The vertical-intensity (Z) magnetometer is of the induction-type after B. I. Yanovsky's system, equipped with permalloy rods and an astatic magnetic system. The variations of the vertical force can be observed also by means of a universal Z and H local variometer. A constant-temperature compensation of the order of 1 to 2γ per degree has been obtained by means of a special alloy—"calmalloy." By the use of auxiliary magnets, also compensated by calmalloy, the sensitivity of the D-magnetometer can be brought to 2 to 3 minutes to one millimeter of the scale and the sensitivity of the H-magnetometer to 4 to 5γ per millimeter. The sensitivity is determined by the electrical method using Helmholz coils.

The unpacking and installation of the entire set of instruments requires only from 15 to 20 minutes.

Absolute observations will be taken, according to plan, three or four times per month, and variation-observations every six or eight days in diurnal series with readings of the variations every three to five minutes.

For measurements of the potential-gradient a Spindler bifilar electrometer will be used. During the polar night hourly observations of the aurora borealis will be made.

Leningrad, U. S. S. R

CHAPTERS IN THE HISTORY OF TERRESTRIAL MAGNETISM

By A. Crichton Mitchell, D.Sc.

CHAPTER II—THE DISCOVERY OF THE MAGNETIC DECLINATION

1—In Chapter I* it was shown that the compass had been brought into use in northwestern Europe for the purposes of navigation by the year 1187, that its first mention in the literature of that year does not refer to it as being of recent introduction, that the discovery of the directive property of a magnet in the Earth's field must have preceded this application by some considerable time, but that of this time it was not possible to frame any reliable estimate.

Until the end of the sixteenth century, and even later, this directive property of the magnet was the subject of much speculation among philosophers, and the ordinary sequence of treatment might lead us to deal next with the results, such as they were, of these enquiries. This, however, will be postponed until we deal with the first step in advance after the introduction of the nautical compass.

2—The four centuries from 1200 to 1600 witnessed the completed transition from the age in which medieval scholasticism was dominant into that when the art and logic of observation and experiment had vindicated their entry on the field of scientific investigation. But we have to wait until the publication, in the latter year, of Gilbert's *De Magnete* before the foundations of the science of terrestrial magnetism were well and truly laid. Meanwhile, one notable advance had been made. For at least three hundred years before Gilbert's time, it had been noticed that the suspended magnet did not, always and everywhere, point to the exact geographical north. At first, this was explained as being due to the lodestone, by which the compass-needle was magnetised, having different properties in different parts; later on, it was attributed to imperfections in the method of magnetising the needle, or to errors in the observation of its direction relative to the geographical meridian. But gradually it came to be recognised that this divergence was a universal phenomenon, and thus was reached the conception of the magnetic declination, the angle at a given place and time between the geographical meridian of the place and the direction of a magnet freely suspended in a horizontal plane.

The question which immediately presents itself is that relating to the origin of this conception—by whom, when, and in what circumstances, this phenomenon of magnetic declination was first observed. But, as in the analogous question of the nautical compass, we have no extant record of any such observation—the earliest references are found to be imperfect and obscure and thus the question cannot be answered in precise terms of persons, dates, and places. In the strict sense of the term, therefore, we cannot speak of the *discovery* of the declination and it would be more correct to refer to the history of the matter as being

*Terr. Mag., 37, 105-146 (1932).

that of the gradual evolution of the conception of declination. This view of the question being adopted, the most suitable method of treatment is indicated. We do not, as in Chapter I, deal with each claimant to the honour of discovery, for this would tend to obscure the historical process, and we proceed to examine the records in their historical order, as far as that can be ascertained.

3—The year 1187 A. D. has been referred to above as the date of the earliest mention in literature of the compass being employed in navigation. For several reasons, the discovery of the directive property of a suspended magnetic needle must have preceded that year by a considerable time. First, because some interval would necessarily elapse before that property was applied to the construction of a primitive compass. Second, it is not referred to, when first mentioned, as a novelty [**1**]. Third, the compass is found in use in northwestern Europe by 1187, in the Mediterranean by 1204, in the Indian Ocean (or the Persian Gulf) by 1220, and in China at some uncertain, but slightly earlier date. In whatever part of the world this extension originated, the process must have occupied many years. Any estimate of this interval must be conjectural and all that it is possible to say is that the stage was set ready for the recognition or observation of the declination as soon as the directive property of the magnet had been discovered.

There is, however, one claim made for an observation of declination at a date very much earlier than can be easily credited. In 1897, Wylie stated [**2**] that I-shing, a Buddhist priest and Chinese Imperial astronomer who lived about 700 A. D., was acquainted not only with the directive property of the magnet but also with the fact of its direction in China being eastwards from the geographical meridian. As already shown in Chapter I [**3**], Wylie gave no exact reference to any original source of his information and although it has been searched for by Hirth [**4**] and Hashimoto [**5**], nothing of the kind has been found. One of the many curiosities in the early history of the subject is that while Wylie was exceedingly careful in giving precise references in all his discussions on Chinese literature, he gave none at all in this instance. The principal facts in the life and work of I-shing are given in the *T'ang-shu*, in which Hashimoto [**6**] found a passage bearing a certain resemblance to the quotation made by Wylie. But this passage has no connection with the magnet and Hashimoto concludes that Wylie translated it incorrectly. Pending further investigation, this supposed mention of the declination must be passed over as having no significance for the present purpose.

4—Another possible reference to magnetic declination also comes from China. It is based on a passage in the Chinese cyclopedia *Mung-khi-py-than*, written by Shonkua, who lived 1030-1093 A. D. It has been translated as follows: "A geomancer rubs the point of a needle with the lodestone to make it point to the south, but it will always deviate a little to the east, and not show the south; that to use the needle, it may be put on water, but it would not be steady; and also it may be put on the nail of a finger or on the lip of a bowl, but it is too apt to drop, because its motion is very brisk; that the best method is to hang it by a thread, and to prepare the contrivance, one has to single out a fine thread from a new skein of floss silk and fix it with a piece of beeswax

on the middle of the needle, the latter to be hung up where there is no wind; that the needle would then always point to the south; that, on rubbing a needle with a lodestone, it may happen by chance to point to the north, and he (the author) owned needles of both sorts, and that no one could as yet find out the principle of it" [7].

This passage, or its substance, also appeared in the supplement [8] to the same cyclopedia, and also in later Chinese works. It is generally on these latter that commentators have based their conclusions [9], its first sentence being quoted, not invariably with its important context, in support of the claim now under reference. But careful consideration of the whole passage proves that the author's attention is concentrated on the transmission to the needle of the directive property and on the demonstration of that property. Further, the deviation from the meridian is not regarded as a separate physical phenomenon but as an accidental result due to imperfect support or suspension of the magnetised needle. The passage cannot, therefore, be accepted as proof of Chinese knowledge, in the eleventh century, of the magnetic declination. In support of this conclusion, the experience of Father Ricci and other Jesuit missionaries in China, about the beginning of the seventeenth century, may be quoted. They were permitted to take part in the proceedings of the Chinese Tribunal of Mathematicians, and had considerable difficulty in persuading the Tribunal that the geographical and magnetic meridians were not coincident. It was only after actual demonstration of the divergence of 2° between them, that the Tribunal accepted the fact of declination. In 1696, Le Comte reports [10] that the Chinese were still firmly persuaded that the magnetic needle always pointed to the south. In 1870, Amiot [11] found that the Chinese still accepted the declination at Pekin as being 2°, thus showing that they obtained their first knowledge of the matter from Father Ricci's demonstration. Another piece of evidence is the fact that when the Chinese used the magnetic needle to determine direction, they did not take the declination into account. Thus, the east and west walls of Pekin, built in the time of the second emperor of the Ming dynasty, do not run exactly north and south, but deviate 2½° from that direction [12].

Hashimoto [13] claims to have found a reference to magnetic declination in a passage in the *Tung-hua-lu*, written towards the end of the twelfth century. The passage is exceedingly obscure and almost untranslatable in modern terms. That it refers to the lodestone or the magnet, or to magnetic declination, is certainly open to question.

From what has been stated above, the conclusion necessarily follows that our knowledge of magnetic declination did not originate in China.

5—From China, therefore, we have to come to Europe. Very soon after its first mention by Neckam in 1187, several writers refer to the compass in one or other of its primitive forms but none of them appears to know of any departure from the rule, then accepted, that the magnetic needle pointed to the north or to the pole star. The earliest reference to any phenomenon of this kind is to be found in the *Opus Minus* of Roger Bacon, written in 1266. The passage in question is printed in full in the appended notes [14]. In explanation of the behaviour of a suspended magnetic needle, Bacon puts forward the theory that a lodestone resembles the Earth in having north, south, east, and west

parts—a curious anticipation of Gilbert's main thesis of 1600—and that if the needle is touched by any one of these parts, it tends to rest in a direction pointing to the corresponding part of the sky. Whether, or in how far, this theory was peculiarly Bacon's own, is not quite clear, but at all events it appears to have persisted down to, or to have reappeared in, the sixteenth century, and we shall meet with it again in dealing with the historical data of that period. Bacon also criticises those philosophers who, by attributing the virtue of the magnet to the pole star, imagine that it must necessarily point to the north, and thereby neglect the possibility of its pointing in any other direction.

The question now arises whether Roger Bacon (or some contemporary) framed this theory to fit the facts of observation, or whether it was merely one of the many speculations of the age. Against the former alternative, it can be urged that no observational fact is quoted in support of the theory. On the other hand, the bare idea of variation of the needle from the north was entirely foreign to the general trend of thought in that age and must have been suggested by some objective phenomenon. That Bacon did not recognise declination as a universal phenomenon is perfectly clear. The curious point is that although he has been referred to as the father of experimental science, he did not, in this case at least, subject his theory to the test of a few simple experiments. Had he done so, they would have led to two results—one, certain, the other possible. The first would have destroyed his theory; the second might have established the fact of magnetic declination.

In connection with Roger Bacon, it was noted in Chapter I, that many writers have been sadly misled by the forgeries of Dupré [**15**] who represented Bacon as demonstrating the properties of the magnet to Brunetto Latini during a visit to Oxford.

6—Contemporaneous with Roger Bacon and his *Opus Minus*, we have the famous *Epistola* of Petrus Peregrinus, written in 1269 [**16**]. For many years it was supposed to have provided the earliest evidence of a knowledge of the magnetic declination. In 1681, Thévenot made the following statement: "On a cru jusques à cette heure, que la déclinaison de l'Ayman n'a commencé d'estre observée que vers le commencement du dernier siècle. Cependant j'ay trouvé qu'elle varioit de 5 degrez l'an 1269, c'est dans un manuscrit qui m'est tombé entre les mains, avec ce titre *Epistola Petri Adsigerii in super rationibus naturae Magnetis*" [**17**]. Thévenot gave no further particulars as to the origin, character, or location of this document, and this, in part, accounts for his assertion remaining unchallenged for nearly one hundred and fifty years. Writers who came after him did little more than repeat his statement, with or without his name as authority. But there is evidence that this was done with reluctance in some cases [**18**]. In 1800, Cavallo published a translation of the more important parts of the manuscript, having meanwhile discovered it in the library of Leyden University. But he added the significant note that the part relating to the value of the declination appeared "as if it were a note or observation not belonging to the text" [**19**]. Finally, in 1835, Wenckebach published an article which explained the matter fully [**20**]. He showed: (1) That the Leyden manuscript is a fifteenth century (possibly later) copy of a genuine manuscript entitled *Epistola Petri Peregrini de Maricourt ad*

Sygerum de Foucancourt militem, de magnete; (2) that the title of the Leyden manuscript, as given by Thévenot, had been derived from that of the genuine original by the omission of three words and the erroneous conjunction of the "ad Sygerum"; (3) that several copies of the genuine *Epistola* existed in various libraries, but that none of them contained the passage on the magnetic declination. He concluded that the passage in question was an interpolation [**21**]. Bertelli also contributed an elaborate bibliographical study of the *Epistola* [**22**].

The sad fact remains that although this error has been exposed for a century, it has been repeated even in recent times and by some most eminent authorities [**23**].

Recently, Winter [**24**] has put forward the proposal that while Peregrinus may not have known of the declination, it was nevertheless known in his time. Winter's argument is somewhat involved, and the present writer has had difficulty in grasping it. It would seem, however, that he seeks to show that inasmuch as the lodestone compass described in Part II, Chapter I, of Peregrinus' *Epistola* was in reality a compass in which the declination was allowed for, after the manner of the Flemish compasses of the early sixteenth century, it follows that the declination must have been noticed by the time Peregrinus wrote. That there are indications pointing to this conclusion being correct, has already been stated above. But I regret being unable to accept Winter's reasons for it, as drawn from the *Epistola*. The text of Peregrinus is, admittedly somewhat obscure and there may be legitimate doubts, as suggested by Winter, as to the authenticity of the figures which accompany some of the translations. But taking the rendering of the relevant passages as given either by Hellmann, or Sylvanus Thompson, or Bertelli (who collated four manuscripts, along with variants in the readings by Gasser, Libri, and D'Avezac) there is to be found no substantial support for this proposal.

7—So far as records bearing on magnetic declination are concerned, the fourteenth century is nearly a complete blank. The only writer in this period who alludes, perhaps distantly, to the subject is Henry of Hesse, otherwise known as Henry of Langenstein, who lived from 1325 to 1397. He graduated at Paris in 1363, was appointed Professor of Theology at Vienna about 1382, and wrote, among other works, a treatise on astrological matters entitled *Contra Coniunctionistas*. The exact date of this work is uncertain, but most probably it appeared soon after 1373. It contains a passage which runs as follows: "Item in partibus Norweie magnes in uno situ trahit ferrum et in alio propinquo (?) non." This has been represented by Thorndike [**25**] as evidence that Henry of Hesse "was acquainted with the variation of the magnetic needle near the north pole." It appears to the present writer that this conclusion is wider than is justified by Henry's remark and that it would be safer to say that what Henry had observed, or had reported to him, was some abnormality due to local attraction of masses of magnetic iron-ore. In any case, it is evidence that even in 1373 such differences had been observed, and this is a matter of some importance.

8—After Henry of Hesse, another gap of possibly half a century or more brings us to evidence of an entirely different kind, and which at one time was widely accepted as being of fundamental importance in

the history of terrestrial magnetism. In 1780, Formaleoni found in the library of St. Mark at Venice, a map or chart prepared by Andrea Bianco and dated 1436 [**26**]. According to Formaleoni [**27**], magnetic declination had been observed by Venetian navigators early in the fifteenth century and this knowledge enabled them to correct their charts in so far as these depended on compass-bearings. As evidence of this but, be it noted, the only evidence—he refers to a figure printed on Bianco's map. It shows one set of lines radiating from the north point of a compass-card, and a corresponding set radiating from a point about 22½° *west* of the north point. He suggested that this angle represented the declination.

Formaleoni's conclusions from Bianco's map, or diagram, were accepted by Humboldt [**28**] and Libri [**29**] and also in more recent times by Mottelay [**30**] and Bauer [**31**]. But they are no longer credited, especially after Bertelli's criticisms of 1868 [**32**] and 1892 [**33**]. It has to be noted that the declination indicated by the figure in Bianco's map is shown as westerly, whereas all available information on the subject shows that the declination over Europe in 1436 was easterly. The matter has again been dealt with recently by Heathcote [**34**]. The general conclusion is that while the exact purpose of these sets of radiating lines is not perfectly clear, Bianco's map does not show the declination and that the figure in question has no relation thereto.

Another early map is that referred to by Libri [**35**], and is now in the Bibliothèque Nationale, Paris [**36**]. It forms part of a manuscript containing the poem *La Sfera* by Goro Dati [**37**], and is referable to the early part of the fifteenth century. But that it contains, as Libri stated, an indication of the declination is extremely doubtful. It includes a diagram in which an arrow is placed near (but not exactly over) the north point of a compass-card. But it is fairly clear that this unsymmetrical position of the arrow may have been due to carelessness in drawing and not to design. Indeed, cases have been found in which the arrow inclines sometimes to one side, sometimes to the other, of the north point. Hence this map cannot be accepted as bearing any evidence of a knowledge of declination.

9—For a considerable body of valuable evidence drawn from still another source, we are indebted to the labours of Hellmann [**38**] and Wolkenhauer [**39**]. This is based on the fact that about the middle of the fifteenth century, if not earlier, portable sun-dials were in use, chiefly by travellers, which had attached to them, in the base of each instrument, a small compass which facilitated the correct adjustment of the instrument with its "noon-line" in the geographical meridian. Some of these compasses show a mark indicating the amount of the declination. As the papers of Hellmann and Wolkenhauer supplement each other, it may be convenient to summarise them together.

After calling attention to the manufacture of these portable sun-dials, chiefly at Nuremberg and Augsburg, Hellmann begins his argument by giving sound reasons for the belief that the word "compass" or "compassus" meant nothing more than a horizontal sun-dial provided with a magnetic needle [**40**]. At what date the manufacture of these instruments began in Nuremberg and Augsburg is unknown. Peuerbach, one of the early authorities on dialling, lectured at Vienna from 1454 to

1460. Among other writings, he left behind two documents [**41**] bearing on the present subject, namely, a pamphlet entitled *Canones Gnomonis cum nova tabula* and a manuscript entitled *Compositio Compassi cum regula ad omnia climata*. His pupil, Johannes Müller, better known by his latinised name, Regiomontanus, settled in Nuremberg in 1471 and carried on astronomical work until shortly before his death in 1476 [**42**]. He made sun-dials, and either introduced their manufacture to Nuremberg or, more probably, encouraged their manufacture if that had already been begun.

The next step in Hellmann's argument is to suggest that any maker of sun-dials, with their attached compasses, who was acquainted with the ordinary method of fixing the geographical meridian, must, in course of time, have recognised that, with the noon-line of the instrument in that position, the magnetic needle did not point exactly north but (in Germany at that time) to the east of north. To adjust the sun-dial correctly, it would then be necessary to orient it with the noon-line to westwards of the direction of the magnetic needle. The procedure would then be to mark on the compass-dial a point corresponding to the deviation of the needle and to orient the instrument until the needle stood over that point. The north point of the instrument would then indicate the geographical north. In whatever manner the process was gradually evolved, the fact remains that sun-dials have been found which show quite clearly the difference between the geographical and magnetic meridians, generally by a mark on the compass-dial to the east of the north point. A letter written by Hartmann [**43**] in 1544 shows that he had observed the declination at Rome in 1510 and found it to be 6° east, whereas it was 10° at Nuremberg. This observation—the earliest of its kind on land—was very probably made with the compass of a portable sun-dial, for it is known that Hartmann was an expert in the construction of these instruments [**44**].

With regard to these sun-dials, Hellmann referred to the instrument found by Le Monnier in Paris [**45**]. It was constructed by Bellermatus, is stamped with the year 1541, and shows the magnetic meridian making an angle of about 7° east with the north point [**46**]. Presumably, this relates to Paris. Wolkenhauer was able, however, to go much further back [**47**]. He called attention to a sun-compass found by E. Mayer [**48**] in the Spitzer collection of antiques at Paris. It is dated 1453 and shows a deviation of the needle from the noon-line. Other instruments of similar kind found by Wolkenhauer are of dates 1451, 1456, 1470, and 1511, all of them showing an easterly deviation of the magnetic needle [**49**]. Finally, there are good reasons for believing that they had been constructed at Nuremberg.

In confirmation of the conclusions towards which the foregoing evidence points, Wolkenhauer referred to certain early road-maps of Germany which were, either directly or indirectly, the work of Erhard Etzlaub of Nuremberg [**50**]. Of these maps, six copies are still extant. Each has at the side or bottom the figure of a compass, similar to that attached to a portable sun-dial, showing an eastward deviation by about 11¼°. That this deviation was clearly recognised at the time is proved by the instructions, printed at the top of the map, for the use of the compass in travelling by the map. It is generally believed that these maps were issued about 1492.

10—Since the beginning of the nineteenth century, the most general opinion regarding the discovery of the magnetic declination has been that it was first observed by Christopher Columbus during his first voyage to the West Indies in 1492. Until 1790, the only record on which this claim could be based was the biography of Columbus, written by his son Fernando. After that date, Navarette, Humboldt, and, especially, Bertelli, founded it on the Las Casas edition of the *Journal* of Columbus. Later opinion inclined towards the view that the declination was known in western Europe before 1492, and that what Columbus may be credited with is the discovery that its amount diminished, became zero, and then turned westwards, as he sailed westwards across the Atlantic. But even this restricted conclusion has been disputed on the ground that the documents upon which it is based are unreliable.

There is no intention here of embarking on the wide and angry seas of Columbian controversy. But the main results of that discussion have an important relation to the matter now under consideration and it is impossible to avoid their impact upon it. Two other reasons may be adduced in justification of the detailed examination of a claim which would, at this stage, appear to have been disposed of by what has already been stated. The first is that the Columbus claim has been put forward so strongly and in such detail by Bertelli, backed by all the resources of an extensive and profound knowledge of the literature of the subject, that his argument cannot be ignored. The second is that a fresh examination of the original documents, which are reproduced below, throws new light on some aspects of the question. At the same time, an attempt has been made to condense the discussion by acceptance of decisions upon extraneous matters when made by competent and reliable scholars. It will also be noted that, as far as possible, the question at issue is examined independently of any historical evidence already given.

11—The original sources on which the Columbus claim is ultimately founded are: First, the biography [**51**] of Columbus written by, or ascribed to, his son Fernando; second, the *Journal* of Columbus during his first voyage of 1492, edited or summarised by Bartolemé de Las Casas [**52**]. But before proceeding to any examination of these sources, two very important questions must be considered. The first is, as to what extent Columbus was, by education and training, of such attainments as would qualify him to understand the various cosmographic and geophysical questions involved in his project or raised in the course of his voyage. The second is, how far the authors or editors of the original sources mentioned had opportunity of acquiring exact information as to the doings of Columbus, and whether they were qualified to set out that information in a manner at once precise, accurate, and intelligible.

First, then, as to Christopher Columbus himself. The information available regarding his early life is remarkably scanty; most conclusions on such matters must be the result of inference and seem destined to remain in dispute. But it has been established with tolerable certainty that he was born at Genoa [**53**], probably in 1446 [**54**], and was the son of an artisan in very humble circumstances [**55**]. There is no evidence that in his boyhood he received any better education than that usually provided for the children of Genoese artisans, if indeed any institution

for the purpose were then in existence. The statements made by his son and by Las Casas that he attended the University of Pavia cannot be accepted [**56**]. At fourteen years of age, he went to sea, possibly as a sailor, or more probably in some capacity as a trader. How he was employed between that date (1460) and the year 1471, when he arrived in Portugal, is either unknown or at best uncertain. But his own statement that he was engaged as a naval commander under King Rene of Provence is demonstrably untrue [**57**]. Nor can the story of his presence at the sea-fight off Cape St. Vincent be accepted, for it has been proved that this took place ten years after he had settled in Portugal [**58**]. With regard to his educational attainments after reaching manhood, there has been wide divergence of opinion [**59**]. But it can be definitely proved that his knowledge of Latin was, at best, rudimentary [**60**] and in consequence he could not have made that profound study of the science of his time, such as it was, that he claims to have made. It is also probable that he could not write Italian [**61**]. There is no evidence that he was in a position to form any reasoned or independent judgment on cosmographical or geophysical questions. When he did express opinions on such matters, his views had no scientific basis and must have been regarded as absurd, even by the limited knowledge of his own day. His science, if it can be so called, was strongly blended with a religious mysticism which only served to confuse important issues and to lead him into speculations of an extravagant kind [**62**]. The most just estimate we can frame of his general capacity is to represent him as a man, probably of much natural intelligence of an untutored kind, capable of persistent effort, but certainly of no special skill or merit in such matters as navigation, astronomy, or cosmography [**63**]. Without stressing the value of negative evidence, it is probable that with regard to terrestrial magnetism, as then understood, he had no closer acquaintance than the average pilot of his time. If this view be correct, he was not in a position to place any intelligent interpretation on the variations exhibited by compass-needles during the crossing of the Atlantic. Lastly, the character of Columbus has been the subject of widely varying opinion. On the one hand, volumes have been written in support of his canonisation as a saint [**64**]; on the other, he has been denounced as a mendacious impostor [**65**]. As is usual in such cases, the truth lies in neither of these extreme directions. But it has to be admitted, and with regret, that Columbus was prepared at times to represent himself as something other than he was in reality [**66**], to resort to stratagem of a dubious kind in order to secure his end [**67**], and to sacrifice truth in the interests of expediency [**68**]. The venial sin in the world of political chicane has no place in the pursuit of scientific knowledge, and the fact that such charges can be laid to his account must tend to lower the credit of Columbus as an observer and recorder of natural phenomena, and must demand the utmost caution in accepting his statements [**69**].

12—Second, as to Fernando Columbus, his son. He was born in 1488, attended school at Cordova, and acted as page to Prince Juan of Spain. When fourteen years of age, he accompanied his father on the fourth voyage (May, 1502, to November, 1504) [**70**]. In 1509, he accompanied his brother Diego to San Domingo, returning in about six months. By the year 1511, he had settled at Seville and had begun the collection of his famous library, which is said to have included 20,000 volumes,

and of which he prepared more than one descriptive catalogue [**71**]. In later years, he travelled extensively throughout Europe. In 1526, he acted as president of a commission of cosmographers and navigators appointed to undertake the correction of marine charts and had also to deal with the examination and licensing of pilots. From all this we may conclude that he was a man of studious habits and that he was in touch with the nautical science of his country and his time. But whether he was conversant with that science as studied or practised in other countries is a point on which we have no information. He had access to his father's papers and records, and perhaps was as capable as most men of his time of understanding their contents. But his manner of giving these expression leaves much to be desired by the modern reader of his *Historie*, for it is frequently vague and occasionally confused. This may be attributed, in part, to the fact that he had to deal with new phenomena which had not as yet found their systematic explanation. It may also be due to later interpolation or to faulty translation, but of this we cannot judge, as will be explained below.

13—Third, with regard to Bartolomé de las Casas [**72**]. He was born at Seville in 1474. His father accompanied Columbus on the second voyage (September, 1493, to June, 1496). In 1492, he obtained the degree of licentiate at Salamanca University. Several writers state that he sailed with Columbus on the third voyage (May, 1498, to November, 1500), but this is incorrect. His first visit to the West Indies was probably in 1502, when he accompanied Ovando, who had been appointed governor. While in Cuba, where he entered the priesthood, he was a witness of the brutal atrocities committed by the Spanish colonists on the natives and he became convinced of the utter injustice of the *repartimiento* system by which the latter were enslaved. The rest of his life was almost wholly directed towards the amelioration of these conditions, in the face of continual opposition by interested officials and in spite of the detestation of many of his countrymen. Retiring in 1547 from his bishopric of Chiapa, which he only held for three years, he spent the remaining years of his life at Valladolid in the completion of his *Historia de las Indias* [**73**] It had been begun in 1527 but he was still enaged on it in 1561, his eighty-seventh year. He left the manuscript to the college of San Gregorio, Valladolid, with instructions that it was not to be published for forty-five years. But it was not until 1875 that it saw the light. The *Historia* contains ample evidence that he had access to many original sources of information, that he must have had before him some written account of the first voyage of Columbus, and that he had borrowed largely from the biography by Fernando Columbus. It must be emphasised, however, that the *Historia* is a special plea in support of Las Casas' main thesis—the ill-treatment of the West Indian natives by the Spanish adventurers. The author is not concerned with, and was probably unable to understand, problems connected with cosmography and geophysics.

14—We have now to turn to the literary history and character of the original sources upon which we have to depend, and these are sufficiently curious. In 1571, seventy-nine years after Columbus made his first voyage, and sixty-five years after his death, there appeared in Venice an Italian translation by Alphonse Ulloa of Fernando Columbus' biography of his father [**74**]. Of the original from which this translation was

made, absolutely nothing is now known, for it has never been found, either in manuscript or in print. The authenticity of this work has been severely attacked by Harrisse [**75**] and has been defended by D'Avezac [**76**] and others [**77**]. Whatever be the ultimate decision as to authorship and date, it is clear that the writer had before him some more or less systematic account of the voyages of Columbus. But up to the time of publication of Ulloa's translation, and indeed for more than two hundred years afterwards, no such account was known. And this leads to the discovery of the *Journal* of Columbus. In 1789, Charles IV of Spain conceived the idea of establishing at Cadiz a library devoted to naval and maritime affairs, and commissioned Don Martin Fernandez de Navarette to examine public and private libraries in order to secure copies of books and manuscripts bearing on such matters. While thus engaged, Navarette found [**78**] in the archives of the Duke of Infantado two manuscript copies of the *Journal* maintained by Columbus during his first and third voyages. One of these manuscripts is in the handwriting of Las Casas, the other is in a later hand. Otherwise, they are identical. They were not published until 1825 [**79**].

The real difficulties involved in these original sources now begin. With regard to the *Journal*, the Las Casas manuscripts are not simple transcripts of a single original. In some passages, they profess to give the exact words of Columbus. The remainder consists of an abstract or précis, that is, Las Casas' own edition of what happened or of what he supposed did happen. The first fundamental difficulty therefore is that we are entirely unable to prove that what Las Casas left behind is an accurate reproduction, either in the exact words or in the true sense of the original. With regard to that original, it has never been found. There is reason to believe that Columbus sent it, or at least the earlier part of it, to the Spanish sovereigns soon after returning from his first voyage; that the original was retained and a copy returned to Columbus; that this copy was afterwards amplified or edited with certain corrections, and that this corrected copy was retained by Columbus [**80**]. But the copies used by Las Casas in the compilation of his *Historia* must have been different from those used by Fernando in his *Historie*, for these two works disagree in certain particulars. Hence the best we can say for the Las Casas manuscripts is that they consist partly of a transcript and partly of an abstract of a copy of a copy of the original. Indeed, the derivation may have been, and most probably was, even more remote. There has therefore been abundant room for errors in transcription, and for alteration and interpolation. They are certainly not documents which can be accepted without the most serious reservation. Hence, to say with Thacher [**81**] that every word of the *Journal* "was in the Admiral's proper hand," or with Markham [**82**] that Columbus "diligently wrote his *Journal* until the day of his return to Palos," is to represent matters incorrectly and to assert what cannot be proved. Lastly, the *Journal*, as we have it from Las Casas, is exceedingly unsatisfactory from the point of view of the scientific navigator, as Lord Dunraven has shown [**83**].

Second, it will be found that the early authorities—the Las Casas manuscripts, Fernando Columbus' *Historie*, and Las Casas' *Historia* are not always in agreement as to essential matters. This will be dealt with in detail in what follows.

Third, the Las Casas manuscripts have suffered at the hands of transcribers and translators. When he published these manuscripts in 1825 [**84**], Navarette, for some reason now unknown, made alterations in the text and these have been accepted without question, except in one instance, down to the present time. Some of these alterations make radical changes in the record of observations made by Columbus, and have given rise to much discussion and to a certain amount of futile speculation. It is now necessary to go back to the original manuscripts of Las Casas in order to ascertain the exact character of the statements made therein; to assist the reader in forming his own conclusions, photographs of the relative portions of these documents, now [**85**] in the National Library, Madrid, have been obtained and are published here for the first time [**86**]. The necessary corrections in the generally accepted version will be noted in their appropriate place below. It will also be found that the *Historie* of Fernando Columbus has suffered in translation.

15—With this preliminary sketch of the materials at disposal, and of the authors or editors connected with them, the passages which refer, or are supposed to refer, to observations made by Columbus on magnetic declination may now be considered. They consist of four from the Las Casas manuscript of the *Journal*, five from the *Historie* of Fernando Columbus, and two from a letter of Columbus. In each case, the language of the original is given, along with a parallel translation into English. The passages headed *A*, *B*, *C*, *D*, are from Las Casas' manuscripts; *E*, *F*, *G*, *H*, *I*, are from the *Historie* of Fernando Columbus; and *J*, *K*, are extracts from the letter of Christopher Columbus.

A

Domingo 9 de Setiembre

Los marineros gobernaban mal, decayendo sobre la cuarta del norueste [**87**], y, aun a la partida, sobre lo cual les riñó el Almirante muchas veces.

Sunday, 9th September (1492)

The sailors steered badly, falling off to the northwest quarter, and even to one-half of the quarter, for which the Admiral reprimanded them on many occasions.

B

Jueves 13 de Setiembre

En este día, al comienzo de la noche, las agujas noruesteaban, y, a la mañana nordesteaban [**88**] algun tanto.

Thursday, 13th September (1492)

On this day, at the beginning of the night, the needles declined to the northwest, and in the morning they declined a trifle to the northeast.

C

Lunes 17 de Setiembre

. . . tomaron los pilotos el Norte marcándolo, y hallaron que las agujas noruesteaban una gran cuarta, y temían los marineros, y estaban peñados y no decían de que. Conociólo el Almirante, mandó que tornasen a marcar el Norte en amaneciendo, y hallaron que estaban buenas las agujas; la causa fué porque la estrella que parece hace movimiento y no las agujas [**89**].

Monday, 17th September (1492)

. . . the pilots took the position of the North Star, marking it, and they found the needles declined to the northwest a good quarter, and the sailors were afraid and were troubled and did not say for what reason. The Admiral took cognisance of this fact and ordered them to take the position of the North Star again at dawn, and they found the needles were good. This was because the stâr which appears, moves, and the needles do not.

D

Domingo 30 de Setiembre

Nota: que las estrellas que se llaman las guardias, cuando anochece, están junto al brazo de la parte del Poniente, y cuando amanece están en la línea debajo del brazo al Nordeste, que parece que en toda la noche no andan salvo tres líneas, que son nueve horas, y esto cada noche; esto dice aquí el Almirante. También en anocheciendo las agujas noruestean [**90**] una cuarta, y en amaneciendo están con la estrella justo; por lo cual parece que la estrella hace movimiento como las otras estrellas, y las agujas piden siempre la verdad [**91**]

Sunday 30th September (1492)

Note: that "the stars which are called the guards, when night falls, are near the arm in the west, and at dawn they are on the line below the arm to the northeast, as it appears that during the night they do not go more than three lines, which are nine hours, and this each night." The Admiral says this here. Also at nightfall the needles decline to the northwest one quarter and at dawn they are exactly in the direction of the North Star; by which it appears that the North Star moves as do the other stars and the needles always demand the truth.

The five passages from the *Historie* of Fernando Columbus are as follows. The text is taken from Caddeo's edition [**92**].

E

Capitolo XVII

Ma, essendo poi corsi altre cinquanta leghe verso Ponente, a XIII di Settembre trovò che da prime notte norvesteavano le calamita d' bussoli per mezza quarta, e l'alba norvesteava poco più d'altra mezza; da che connobe che l'agucchia non andava a ferire la stella che chiamiam Tramontana, ma un altro punto fisso e invisible. La qual varietà fino allora mai non aveva conosciuto alcuno: e però ebbe giusta causa di maravigliarsi di ciò. Ma molto più si maraviglio il terzo dì, nel quale era già corso quasi cento leghe più avanti pur per quel paraggio; perciocche le agucchie da prima notte norvesteavano già con la quarta; e la mattina tornavano a percuotere nella medisima stella.

Chapter XVII

On 13th September (1492), he found that at nightfall the needles of the compass varied half a quarter to the northwestwards, and at break of day half a quarter more; by which he understood that the needle did not point at the North Star but at some other fixed and invisible point. This variation no man had observed before and therefore he had occasion to be surprised at it. But he was more amazed the third day after, when he was almost 100 leagues further, for at night the needles varied about a quarter to the northwest, and in the morning they pointed to the star [**93**].

F

Capitolo XIX

Nè però, quantunque l'Ammiraglio ponesse mente a tutti questi segni, si scordava di quelli del cielo, nè i corsi delle stelle. Laonde in quel paraggio notò con grande ammirazione che di notte le guardie stavano giustamente nel bracchio dell'occidente; e, quando aggiornava, si ritrovavano nella linea sotto il braccio a Nordeste, da che comprendeva che in tutta la notte non camminavano se non tre linee, che sono nove ore; e questo provava egli ogni notte. Parmiente notò, che da prima notte le agucchie Norvesteavano per tutta una quarta, e, quando aggiornava, stavano giustamente con la stella. Per le quali cose i piloti erano in grande affamo e confusione, fiu che egli loro disse di ciò essere cagione il cerchio, che

Chapter XIX

Although the Admiral took note of all these signs, he did not forget the signs of the sky or the course of the stars. He therefore noted with great admiration that at night the "pointers" stood exactly on the arm of the west, and when it was dawn they were found in the line under the arm to the northeast, from which he understood that during the night they only moved three lines which are nine hours, and this he proved every night. He likewise noted that at the early evening (30 September) the needles northwested a whole quarter, and at dawn they were exactly with the star. At this, the pilots were in great anxiety and confusion, until he told them that the reason was the revolution of the Pole Star round the

la stella Tramontana fa, circondando il Polo; il quale avvertimento diede lor qualche conforto; perciocchè in fatti per cotai differenze temevano di pericolo nel cammino, in tanta distanza e diversità di paesi.

Pole; which news gave them some comfort, because such differences made them afraid of danger in such unknown regions.

G

Capitolo LXIII

Questa mattina le aguglie fiammiglie norvestavano, come sogliano, una quarta; e le genovesi, che solevano conformarsi con quelle, non norvestavano so non poco; e per l'avvenire hanno a norvestare andando il Leste, che è segno che ci ritroviamo cento legha alquanto più all'occidente delle isole de gli Astori; perciocche, quando furono appunto cento, allora era in mare poca ciba di ramuscelli sparsi, e le aguglie fiammiglie norvestavano una quarta, e le genovesi percotevano la Tramontana; e, quando saremo più al Leste nordeste, faramo alcuna cosa. Il che si verificò subito la Domenica seguente a XXII di Maggio. Dal quale indicio, e dalla certezza del suo punto conobbe allora che si ritrovava cento leghe lontano dalle isole de gli Astori; di che egli si maraviglia, e attribuisce la cagione alla differenza della calamita, con che si temperano le aguglie; perciocche fino a quella linea tutte norvestano una quarta; e quivi le une perseverano, e le altre, che sono le genovesi, percuotono giustamenta la stella. E ancor si verificò il medismo il seguente giorna a XXIIII di Maggio.

Chapter LXIII

This morning (20 May 1496) the Flemish compass-needles northwested a quarter as usual, and those of Genoa, which used to agree with them, did not except slightly, but after sailing eastwards they northwest more, which is a sign that we are 100 leagues or somewhat more to the west of the Azores; for when we were just 100, there were but few scattered weeds in the sea; and the Flemish needles northwested a quarter, those of Genoa pointing to the North Star; and when we were somewhat further east-northeast, they will alter again, which was verified on the Sunday following, 22 May; by which, and the certainty of his position, he found he was 100 leagues from the islands of the Azores, which he was surprised at, and assigned this difference to the several kinds of lodestone by which the needles are made; for till they reached that line, they all northwested a quarter, and there some held it, those of Genoa cutting the north point exactly. This was most clearly verified on the following day, the 24th of May.

H

Capitolo LXVI

E, quanto al norvestare, io credo che la stella abbia la proprietà dei quattre venti, come l'ha ancora la calamita; che, se toccano col Levante, dimostrerà il Levante e altresì il Ponente, o il Settentrione, o l'Ostro; e però colui che fa le aguglie copie con panno la calamita in modo che non resti di fuori, eccetto che la parte settentrionale, cioè quella che ha virtù di condurre l'acciaio a percotere la Tramontana.

Chapter LXVI

As to the northwesting, I believe that the star has the properties of the four winds, as has the lodestone; that when it touches the east, it will point to the east, and in like manner the west, north, and south; and for that reason, he who makes the compass-needle covers the lodestone with a cloth, all but the north point of it; namely, that which has the virtue of making the steel point to the north.

I

Capitolo LXII

Medisimamenta dice, che quella stessa notte, che fu il Giovedì a XVI di Agosto non avendo fino allora norvestato, le aguglia norvestearono in fretta più d'una quarta e mezza, e alcune mezzo vento, senza che in ciò vi potesse essere errore, perdre sempre erano stati molto vigilanti per notar ciò.

Chapter LXII

He (Christoper Columbus) also says that this same night, being Thursday 16th August (1498), the compasses, which till now had not northwested, did so at this time, at least a quarter and a half, and some of them two quarters; wherein there could be no mistake, because several persons had always watched to observe it.

The two remaining passages from the Columbian documents which must be quoted are from the letter written by Columbus from Haiti on October 18, 1498, and addressed to the Spanish sovereigns [**94**]. It gives his description of the third voyage, and includes the following.

J

Quando yo navegué d'España á las Indias, falló luego, en passando çient leguas á poniente de los Açores, grandissimo mudamiento en el cielo y en las estrellas y en la temperatura del ayre y en las aguas de la mar; y en ésto e tenido mucha diligençia en la experiençia, fallo que de septentrión en austro, passando las dichas çient leguas de las dichas islas, que, luego, en las agujas de marear que fasta entonçes nordesteavan, noruestean una quarta de viente todo entero.

When I navigated from Spain to the Indies, I found that, immediately after passing a hundred leagues to the west of the Azores, there was a very great change in the sky and in the stars and in the temperature of the air and in the waters of the sea. I have used much care in verifying this. I found that from north to south, passing there the said 100 leagues from the said islands, immediately the needle of the compass, which up to then had turned to the northeast, turned a full quarter of the wind to the northwest.

K

Yo siempre leý qu'el mundo, tierra y agua, era espérico, y las auctoridades y esperiençias que Ptolemeo y todos los otros qu'escrivieron d'este sitio davan y amostraban para ello así por ecclipses de la luna y otras demonstraçiones que hazen de oriente fasta occidente, come de la elevaçión del polo de septentrión en austro, agora ví tanta disformidad, como yo dixe; y por ésto me puse á tener esto del mundo, y fallé que no era redondo en la forma qu'escriven, salvo que es de la forma de una pera que sea toda muy redonda, salvo allí donde tiene el peçón, que allí tiene más alto, ó como quien tiene una pelota muy redonda, y en un lugar d'ella fuesse como una teta de muger allí puesta, y qu'esta parta d'este peçón sea la más alta y más propinca al çielo, y sea debaxo la línea equinoçial, ye en esta mar Occéana, en fin del oriente (llamo yo fin de oriente adonde acaba toda la tierra y islas). y para ésto allego todas las razones sobre escriptas de la raya que passa al occidente de las islas de los Açores çient leguas de septentrión en austro, que, en passando de allí al poniente, ya van los navíos alçándose hazia el çielo suavamente, y entonçes se goza de más suave temperançia, y se muda el aguja del marear, por causa de la suavidad, d'esa quarta de viento, y quanto más va adelante y alçándóse, más norvestea, y esta altura causa el desvariar del çírculo que escrive la estrella del norte con las guardas. y quanto más passare junto con la línea equinoçial, más se subirán en alto y más differencia avrá en las dichas estrellas y en los çírculos d'ellas.

I have always read that the world, land and water, was spherical, and authoritative accounts and the experiments which Ptolemy and all the others have recorded concerning this matter, so describe it and hold it to be, by the eclipses of the moon and by other demonstrations made from east to west, as well as from the elevation of the Pole Star from north to south. Now, as I have already said, I have seen so great irregularity that, as a result, I have been led to hold this concerning the world, and I find that it is not round as they describe it, but that it is the shape of a pear which is everywhere very round except where the stalk is, for there it is very prominent [**95**], or that it is like a very round ball, and on one part of it is placed something like a woman's nipple, and that this part, where this protuberance is found, is the highest and nearest to the sky, and it is beneath the equinoctial line and in this Ocean sea at the end of the East. (I call that "the end of the East," where end all the land and islands.) And in support of this, I urge all the arguments given above, concerning the line which passes from north to south a hundred leagues west of the Azores. For in passing hence to the westward, the ships went rising gently towards the sky, and then the mildest weather was enjoyed, and the needle shifted a quarter of the wind on account of this mildness, and the further we went, the more the needle shifted towards the north west, and this elevation causes the variation of the circle which the North Star describes with the guards, and the nearer I approached to the equinoctial line the more they rose and the greater difference there was in the said stars and in their orbits [**96**].

16—Before dealing with these passages, it is necessary to explain some of the terms employed, and to assign, as nearly as possible, the position at sea to which each passage refers.

In Columbus' day, the compass-card was divided into eight "winds," separated from one another by the directions north, northeast, east, southeast, south, southwest, west, and northwest. Each of these "winds" of 45° each, was subdivided into four "quarters," each of 11¼°. Hence a "quarter" corresponded to what is now known as a "point". Whether further subdivisions were marked on the card is uncertain. Probably they were estimated by eye.

In the account, by Fernando Colombus, of the second voyage (*G* above), there are references to "Flemish" and "Genoese" compasses. In the Genoese compass, the north-pointing end of the magnetic needle was fixed under the compass-card so as to correspond with the north point of the card. The direction of this latter point would then be affected by declination, and allowance would have to be made for this in laying a ship's course. In the Flemish compass, however, a different arrangement was adopted. The sailors of northwestern Europe had found that the needle did not point exactly to the geographical north; that it made an angle of about a point, or 11¼°, eastwards, with that direction. In order to correct for this deviation, or declination, they fixed the north-pointing end of the needle 11¼° to the east of the north point of the compass-card. The latter then gave them the true north [97]. Obviously, a compass so arranged would only give correct indications if used in a region where the declination was 11¼° east, and so long as it remained at this amount and of this sign. It should also be noted that the amount by which the Flemish compasses used by Columbus were corrected is uncertain, but it does not appear to have exceeded 11¼°. Gilbert writing in 1600, mentions corrections varying from one-half to two-thirds of that amount. There is no information as to the type of compass used on the first voyage of Columbus in 1492. Most probably it was a Genoese compass. It will be found later on that the fact of both kinds of compass being used on the second voyage is of considerable importance.

The passages quoted also make reference to the stars then known as the "Guards." These are now known as the "Pointers," and are the stars α and β of the constellation Ursa Major. A line through these stars passes close to the Pole Star (α Ursa Minor). Columbus makes several references to this latter star, and had some very peculiar ideas as to its diurnal motion on the celestial sphere [98]. In 1492, its distance from the celestial pole was 3° 26′.7 and its right ascension 2° 50′.0. Hence, at "nightfall," which, for the date and latitude concerned, may be taken as being soon after 6 P. M. local mean time, the Pole Star would be seen in the northern sky at an altitude of 28° 09′, and nearly due east of the celestial pole. At dawn, it would be at an altitude 28° 26′, and nearly due west of the celestial pole [99]. The two positions, at nightfall and dawn, would be separated by an arc of nearly 8°.

The question arises—and will be fully dealt with later—as to the fiducial point from which Columbus reckoned the easting or westing of his compass-needles. Nothing of a positive character is stated in any of the original documents, the *Journal* or the *Historie*. But, as will be shown below, there is a possibility that, in his earlier observations, for

example, on September 13 and 17, 1492, he used the azimuth of the star Polaris as being that of true north and reckoned the variation therefrom. He would thereby ignore the fact that this star was nearly $3\frac{1}{2}°$ from the celestial pole.

It only remains to add that the quotations given above relate to voyages, dates, and positions at sea, as follows:

Quotation	Voyage	Date	Latitude north ° ′	Longtiude west ° ′
A	First, outward	September 9, 1492	28 20	20 21
B, *E* (1st part)	First, outward	September 13, 1492	28 21	29 16
C, *E* (2nd part)	First, outward	September 17, 1492	27 38	36 30
D, *F*	First, outward	September 30, 1492	25 58	50 55
G	Second, homeward	May 20, 1496	About 20 leagues west of Azores	
H	Third, homeward	July, 1498	6	40
I	Third, homeward	August 16, 1498	11	63
J, *K*	Relate to observations made when 100 leagues west of the Azores but to no particular date.			

17—The quotations from the original sources have now to be examined in order to ascertain their meaning and to deduce therefrom what Columbus actually observed. This is a task of no slight difficulty, for the most cursory perusal of these quotations will show their exceeding obscurity. They have been examined in some detail by Bertelli [**100**], Wolkenhauer [**101**], Errera [**102**], and Magnaghi [**103**], but the conclusions reached by these eminent critics are by no means concordant.

The first passage, *A*, has apparently little connection with the question of magnetic declination. The reason for its inclusion is that it was brought forward by Bertelli [**104**] as indicating the result of steering courses uncorrected for declination.

As given by Navarette, and as used by Bertelli, it represents the steersman as turning from the prescribed westerly course into another lying somewhere between north and northeast; that is, through an angle between 90° and 135°. But the meaning of the phrase "aun a la media partida" is very far from clear, if we accept Navarette's transcription and Bertelli's argument founded thereon.

Bertelli's explanation of the matter forms part of his more general hypothesis that Columbus knew nothing of the fact of magnetic declination until September 13, four days afterwards. His argument may be stated thus. On September 9, the ships were in a region of easterly declination, although neither Columbus nor any of his pilots knew it. The course actually steered would thus lie to the north of the westerly course prescribed by Columbus. But while the steersman went entirely by compass, Columbus navigated by astronomical observations, and was thus able to check errors in steering.

Bertelli's view cannot be accepted for several reasons. First, while it is true that the ships were then in a region of easterly declination, it is highly probable that the amount of the declination was too small to be detected by the rudely divided compass-cards in use at that time. About 40 years afterwards, De Castro [**105**] found the declination at Lisbon to be $7\frac{1}{2}°$ east, and in 1538, at Las Palmas, it was $5\frac{1}{2}°$ east.

We may therefore take it that, at the position reached on September 9, 1492, the easterly declination did not exceed 3°. Schott [**106**] has made another estimate and finds it 2°. Thus the amount of the declination was altogether too small to have an immediately appreciable effect on the steering. Second, even supposing the error in steering, due to supposed ignorance of the fact of declination, were large, it could in no circumstances account for such an enormous departure, exceeding 90°, from the course laid down. Third, it was impossible for Columbus to check the steering of the ship from one moment to another by astronomical observations. Indeed, there is no mention in the records of his having attempted anything of the kind.

PLATE I

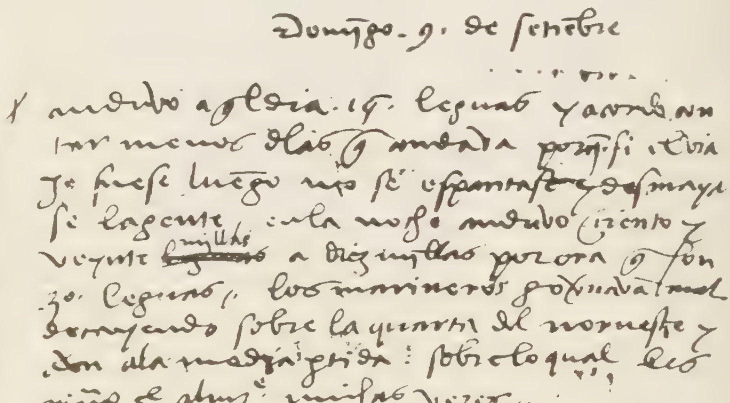
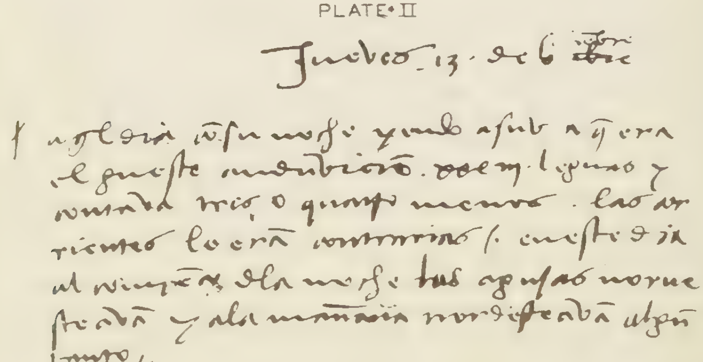


PLATE II



Magnaghi [**107**] has suggested that the steersman, in turning northwestwards from the prescribed westerly course, was attempting to allow for leeway due to currents. But it is improbable that a steersman would make any such attempt without specific instructions.

Since a departure from west to a course nearly northeast would have been practically a return in the homeward direction, Lord Dunraven [**108**] suggested a mutiny of the crew and an attempt to return to Spain. But this is not supported by any available evidence.

The whole matter assumes a totally different aspect if the original documents are examined. The transcription of the passage *A*, in the *Colección* [**109**] of Navarette gives northeast as the direction to which the ship fell off. But from the photographed copy, Plate I, of the Las Casas manuscripts it will be seen that the word used is not "nordeste," as transcribed by Navarette, but "norueste." This is supported by what Las Casas stated in his *Historia* [**110**], where he gives northwest as the new direction, not northeast. This explains the passage quite sufficiently, including the phrase "aun a la media partida." What it meant to convey was that the steersman allowed the ship to fall away from west *towards* northwest, and even to the extent of half that departure, that is, by two points, or 22½°. This would be quite possible as an example of careless steering in such ships and would not require astronomical observations for its detection, because it would be immediately noticeable.

The passage *A* has thus no bearing on the question of declination, or on that of Columbus' knowledge, or ignorance, of the existence of that quantity.

18—We therefore pass on to consider the quotation *B* from Las Casas; and along with this, as dealing with the same event, we take the first sentence of the passage *E* from the *Historie* of Fernando Columbus.

The first matter which calls for attention is a serious discrepancy between these two accounts. The Las Casas manuscript (see Plate II) states that the compass-needles declined northwestwards on the evening of September 13, 1492, and on the following morning they declined a trifle towards northeast. In Navarette's transcription [**111**] the latter is given as northwest, an error or substitution, which is obvious on reference to the original. On the other hand, the *Historie* of Fernando Columbus, as quoted in passage *E*, makes the morning deviation to the northwest. Not only so, this quotation gives the evening deviation as half a quarter and that of the morning half a quarter more—that is, the difference between the evening and morning directions of the compass-needle was nearly 5½°. Turning to Las Casas' *Historia de las Indias* [**112**], we find the morning direction given as "*nordesteaban, que es decir, que se acostaba la flor de lis a la mano derecha del Norte,*" thus confirming what we find in the Las Casas manuscript.

There is thus distinct and irreconcilable conflict between the two statements, but how this arose is far from easy to explain. Several possible solutions present themselves. Las Casas and Fernando Columbus may have been quoting from different copies of the *Journal*; there may have been errors of transcription by one or other or both authors; there may have been errors in translation by Ulloa, the editor or translator of the *Historie*. In the absence of the originals, both of the *Journal* and of the *Historie*, it is impossible to settle the point def-

initely. But, after the important correction has been made in Navarette's transcription of the Las Casas manuscript, it will be seen that Las Casas' is the more acceptable version of what took place.

First, assuming that Columbus used the direction of the Pole Star as being that of true north, it has to be remembered that his fiducial point moved nearly 8° across the sky in a westward direction during the night of September 13-14. Hence, if we make the perfectly reasonable supposition that there was little or no change of declination during the night's sail (about 50 miles), a deviation slightly to westwards of the Pole Star at nightfall would be equivalent to a nearly equal deviation to eastward of the Pole Star in the morning. Regarded in this way, the statement made in Las Casas' edition of the *Journal* under September 13, 1492 is consistent with itself and with what we know of the conditions.

Second, on the same assumption, Fernando Columbus' statement would make the total motion of the compass needle during the night equal to "half a quarter," that is, nearly 5½°, *plus* the westwards motion of the Pole Star—in all, about 13½°. This, to put it mildly, is so exceedingly improbable within a distance of 50 or 60 miles, that it must be entirely rejected.

Third, discarding the foregoing assumption and supposing that Columbus, recognising the fact of the Pole Star having an appreciable N. P. D., measured compass-deviation from the true north, it is impossible to account for the compass-needle varying westward at night *and* eastward next morning. The ships were not, at the time, in a region in which the distribution of declination was highly irregular, and the only possible explanation—on the above hypothesis—would be either careless determination of the direction or the intervention of some extraneous disturbing agency.

Fourth, if we again assume that Columbus measured deviation from the true north, Fernando Columbus' statement is conceivably true as regards the *manner* of the variation recorded but, as to its amount, namely, 5½°, it cannot, for reasons given above, be accepted.

Thus the balance of argument is in favor of the statement made in Las Casas' edition of the *Journal* and is in support of the hypothesis that Columbus measured the variation from the Pole Star. This latter point will be dealt with again.

Two additional comments have to be made on these entries relating to September 13, 1492. The first is that Fernando Columbus wrote his *Historie* nearly forty years after the events which he undertook to describe. By that time, the fact of the magnetic declination was well known, and possibly that of its variation in space. Looking back on what he personally knew of the history of the matter and believing that a continuous change in declination from east to west took place in the westward crossing of the Atlantic, he might conclude that on this westward track the westerly variation on the morning of September 14 should be still greater than that of the previous evening. Accordingly, he made it so, without examining the question as to the point from which his father had reckoned the declination. In the second sentence of the passage *E*, he states that no one had observed such variations before and that his father was surprised at them. This would appear to be a reflection of his own, rather than an extract from any record. For it is to be noted that there is nothing said by Las Casas,

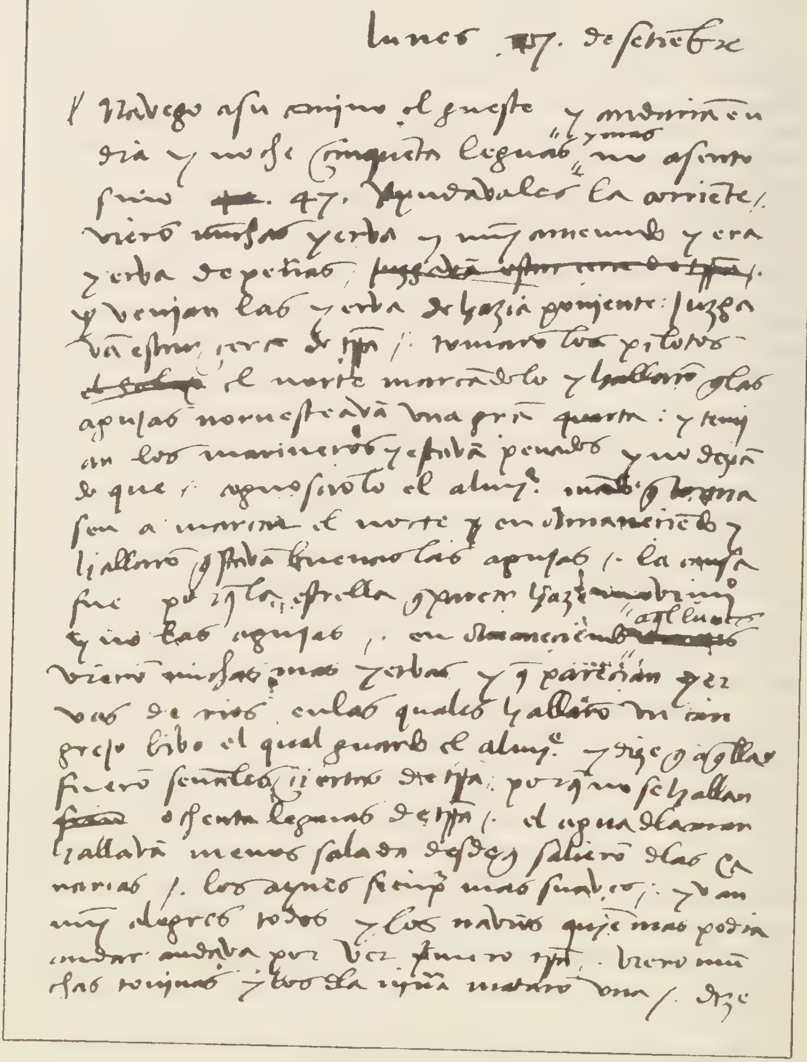
either in his edition of the *Journal* or in his *Historia*, which corresponds to this statement.

The second comment is that we may profitably enquire into the possible reasons which may have led Columbus to make observations on compass-variations during his voyage. Following Navarette [**113**] and Humboldt [**114**], Bertelli [**115**] has claimed for Columbus the discovery, not only of the space-variation of the declination, but of the declination itself. Let us suppose for the moment that this view is correct, and therefore that Columbus sailed from Palos in the fixed belief that, no matter where it might be observed, the compass-needle always pointed exactly north. Why, then, these observations, night and morning, of the direction of the compass-needle? In the belief referred to, they were unnecessary for the navigation of the ship. It is true that there is no record of any observations of the kind during the earlier portion of the voyage. If they were made, it could only have been because the fact of the declination was already known and because it was necessary for correct navigation to ascertain its amount and make allowance for it. If they were not made, Bertelli's claim on behalf of Columbus is founded upon a casual determination of declination whose amount was within the limits of observational error with the instruments then employed. Again, if such earlier determinations were made and if the declination, as asserted by Bertelli, were then unknown, how was Columbus able to detect a small westerly declination on September 13, and yet fail to note the larger easterly declination off the Spanish coast? The inevitable conclusion is that Columbus (or, rather, his pilots) must have been aware of an easterly declination and this would account for there being no record of it in his *Journal*. It would be an accepted fact. Later on, it will be found that this conclusion is supported, if not positively expressed, by his own statements.

Summarising the foregoing examination of the records relating to September 13-14, 1492, it may be stated: (1) That the two accounts by Las Casas and Fernando Columbus disagree as to details, but that the former appears to be the more reliable; (2) that in all probability, Columbus reckoned compass-direction from the azimuth of the star Polaris as giving true north; (3) that on this assumption and taking into account the diurnal change in position of the fiducial point, the observations are consistent with a westerly declination of 1°, or possibly 2°, but the method of observation was much too rough to determine this with any approach to accuracy; (4) that general considerations are all in favor of the view that Columbus, or his pilots, were already acquainted with an easterly declination. If this is correct, Columbus did not discover the magnetic declination. He made observations which indicate that on September 13-14 he was close to the agonic line, but formed no conception of any general kind as to the existence of any such line.

19—The observations made on September 17, 1492, have next to be considered. They are contained in the passage *C* from the Las Casas manuscript (see Plate III), and in the latter part of *E* from Fernando Columbus' *Historie*. They agree in stating that at nightfall the deviation was westerly by a full point, that is, nearly 12°, but that on the following morning the needle pointed to the Pole Star.

PLATE III



The questions we have to answer, if possible, are two. What are we to understand by these observations? How did Columbus interpret them? With regard to the first, we have here again a case which can be best explained on the hypothesis that, up to this date, Columbus measured compass-directions from the Pole Star as representing the true

north, and not from the celestial pole. If he were measuring direction from the latter point, the difference between the evening and morning directions of the compass-needle was fully $11\frac{1}{4}°$. This, of course, is an impossible result and we therefore take the first alternative. In this case the evening observations made the compass-needle point $7\frac{1}{4}°$ west of true north (that is, allowing nearly 4° for the N. P. D. of Polaris). The morning observation made it point 4° west of true north These two observations differed by $3\frac{1}{4}°$, an amount too small for measurement by the rough methods [**116**] then in vogue and which was, as a matter of fact, neglected. The true meaning of these observations therefore is that the compass-needle continued to point nearly true north. So far, then, nothing had been actually observed which proved the existence of a magnetic declination.

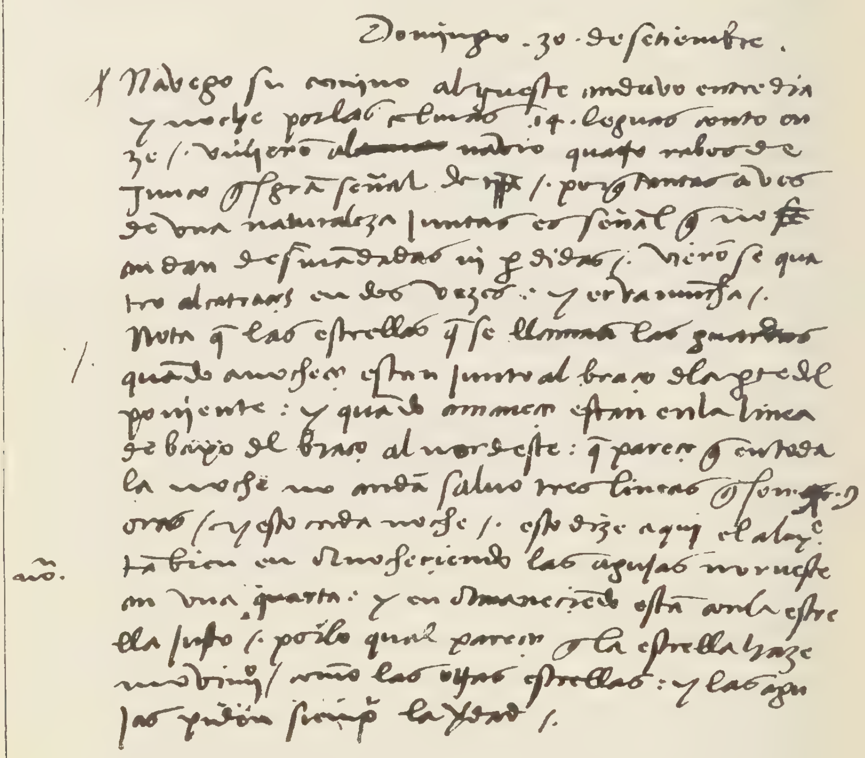
With regard to the second question, as to what construction was put upon these observations by Columbus, we have very little information. The exact extent of his knowledge of the behavior of a compass-needle is unknown to us, and such comment as is made in his *Journal* on these observations is not in agreement with his later statements. If we suppose that Columbus regarded the position of Polaris as being a fixed point on the celestial sphere, the observations ought certainly to have appeared to him as being peculiar. But there are indications in the passages quoted, especially if taken along with the last sentence of passage *D*, that it was only about this time that Columbus began to realise that the star Polaris was not fixed in position, that it had an appreciable N. P. D., and that it revolved round the celestial pole as do the other stars. It is thus possible, though not probable, that the correct interpretation of the phenomenon may have occurred to Columbus. The *Journal*, or Las Casas' edition of it, states that the sailors became afraid. Fernando Columbus says his father was surprised. The cause of this fear or surprise could not have been the discovery of any new and inexplicable fact such as magnetic declination, for such a result the observations did not indicate. The only reasonable hypothesis is, that whereas they had known, and been accustomed to, an easterly declination off the coasts of western Europe, they now found that this would appear to have nearly vanished, and possibly become a westerly declination.

20—The quotations *D* (Plate IV) and *F*, relating to observations on September 30, 1492, do not add anything to what had been recorded already. But the passage *F* again suggests that observations of the direction of the compass-needle were measured from the Pole Star, and not from the celestial pole.

21—We have now to deal with the passage *G* from the *Historie* of Fernando Columbus, and it contains important matter for the present purpose. It deals with observations made on May 20, 1496, while on the homeward run of the second voyage. The position of the ship on that date was somewhere about 120 leagues west of the Azores [**117**].

The passage begins with a reference to "Flemish" and "Genoese" compasses, the arrangements in which have already been explained. Nothing is on record as to the kind of compass used by Columbus on the first voyage, but the passage now under consideration shows that on the second voyage both kinds were used. The first voyage lasted

PLATE IV



from August 3, 1492, until March 15, 1493, and Columbus embarked on the second voyage on September 20, 1493. According to Bertelli, the fact of magnetic declination was unknown to any person before September 13, 1492, on which date, he avers, Columbus discovered it. If this be the case, his discovery could not have been published to the world before his return on March 15, 1493. Now, in the first place, we have no evidence of any such publication. Yet in six months we have the Flemish compasses in use, with their device making allowance for the declination. It is altogether inconceivable that, in this short period of six months, a knowledge of Columbus' supposed discovery could have travelled as far as Holland and could have allowed navigators to confirm it, to devise means of making allowance for it, to introduce the new form of compass, and for this new form to reach Spain in time to be included in the equipment for Columbus' second voyage. The only possible conclusion is that the magnetic declination was known to the navigators of northwestern Europe independently of Columbus. And we may go so far as to regard it as highly probable that Columbus knew of it him-

self when he left Palos on his first voyage. The single fact of the use of both kinds of compass on the second voyage is fatal to Bertelli's claim on behalf of Columbus [**118**].

The same passage, *G*, also refers to the indications given by the two forms of compass. Beyond the fact that the directions of their north points on the compass-card differed by a "quarter," that is, 11¼°—which shows that the Flemish instrument had been fitted for an easterly declination of that amount—the information given is scanty and its meaning is obscure. Apparently, there was a belief on the part of Columbus—confirmed by later documents still to be cited—that in the region 100 leagues west of the Azores, the compass behaved in a peculiar manner. But in what the "difference" consisted, at which Columbus was surprised, is far from clear. In any case, his explanation that it was due to the needles being magnetised by different kinds of lodestone is unacceptable [**119**]. It is in some degree a reflection of the opinion held at the time by some navigators [**120**].

22—In the passage *H*, which relates to July 1496, when Columbus was sailing westwards on his third voyage, and was in a position about latitude 6° north and longitude 40° west, Fernando Columbus gives his own explanation of the "northwesting" of the compass-needles which had been observed on previous occasions. He believes that there is, in each piece of lodestone, some particular part or point which, when rubbed on a steel needle, causes the needle to point to the north. Here he is only repeating what was common knowledge of the time. But he goes on to state that the lodestone has other parts or points which, when so applied, cause the needle to point to the east, the west, or to the south. In support of this statement, he quotes the practice of compass-needle makers, who cover the lodestone with a cloth, "all but the north point of it," when magnetising a needle. It has already been shown, in paragraph 5, that a similar idea was current in Roger Bacon's time.

The curious feature here, however, is that there is no mention of declination, although its existence was common knowledge among navigators when Fernando Columbus was writing his book. It also suggests the conclusion that his father had not formed any clear conception as to magnetic declination and this we find to be confirmed by later documents.

The passage *I*, from Fernando Columbus' *Historie* relates to observations made near the Gulf of Paria on the third voyage westwards. Its substance is so extraordinary that it has generally been rejected entirely by commentators. That the compasses should show no variation from true north during the voyage, and then suddenly change by nearly 17°, or even by 22°, is quite unbelievable. We can only conclude that such effects must have been produced by some extraneous disturbance.

23—Finally, we have the two extracts, *J*, *K*, from the Haiti letter of Columbus, dated October 18, 1498.

In the first, we have Columbus' own statement that until he passed to westwards of a point 100 leagues west of the Azores, the compass-needle pointed towards northeast, and that when he had passed this point, it immediately turned to a direction fully 11° west of north. This is the first time, among the somewhat obscure records available, that we have a tolerably clear statement of what Columbus believed he had found. Yet it presents two difficulties in the way of its unqualified

acceptance. The first is, that a sudden change in direction, of this amount, is altogether improbable. The second comes from the historical point of view. For his statement gives no indication as to the exact stage, in his previous voyages, at which he had framed this conception. It might be quoted as proof that he knew of the easterly magnetic declination before he left, or very soon after leaving, Spain on his first voyage, but the letter does not say so explicitly. All that can be said is that it is not inconsistent with, and even strengthens that conclusion, which, on grounds already stated, has been shown to be highly probable.

In the second passage, *K*, Columbus gives expression to his own peculiar views regarding the changes met with in crossing the meridian 100 leagues west of the Azores. These have no bearing on the question of priority in discovery of the magnetic declination and the passage is only quoted on account of the second explanation which Columbus now gives for the westerly variation of the compass-needle, namely, that it is due to the mildness of the climate, which, in its turn, he attributes to a protuberance of the terrestrial surface in that region.

24—The observations made by Columbus, or credited to him by his editors, biographers, translators, or commentators, have thus been dealt with in detail. But before summarising such conclusions as can be drawn from them, it is well to ascertain whether these observations, or their results, were referred to by any writers between 1592 and 1789, the date of discovery by Navarette of the Las Casas manuscripts.

Bertelli [**121**] has brought forward several witnesses of this kind, the first being a letter [**122**], dated from Cadiz, January 2, 1498, and written by Simon del Verde to Mateo Cini. It contains the following passage: ". . . *lo admirante ha havuto grande animo et ingiegno havere discoperto l'altro mondo opposito al nostro con tante fatiche et sudori et visto la mutatione che fa la tramontana per essere ito di la linea del equinoctiale.* . . ." But this does not credit Columbus with the discovery either of the declination or of its change in sailing westwards. It only refers to the declination and its change as possible difficulties in laying a correct course across the Atlantic. Indeed, one might almost gather from the letter that both of these quantities were already known.

Bertelli [**123**] also quotes a letter, dated January 1519, from Piero di Giovanni di Dino [**124**], in which observations of declination on the Guinea Coast and at the Cape of Good Hope are given. They are among the earliest of their kind. There is full recognition of the declination and its change with position but there is no mention of any observations by Columbus in connection with either. Since the observations by Columbus had not, by that time, been published to the world generally, it must be concluded that both facts must have been reached by others independently of, and even possibly before, Columbus.

The last two references given by Bertelli [**125**] are those to a letter, dated March 6, 1582, by Filipo Sassetti [**126**], and a passage written by Giovanni Maria Sagri in the preface to a book published in 1574 by his brother Nicola [**127**]. Both refer to the declination—a matter of common knowledge by either date—but only in a general manner. Neither makes any mention of Columbus.

Such absence of any reference to Columbus is all the more sharply marked by the fact that none of the writers, in whose works we might expect such reference, mentions his name in this connection. Oviedo

published his history of the Indies [**128**] in 1535, but although he deals at some length with the northwesting and northeasting of the needle, he does not ascribe the discovery to Columbus. His account, it is true, is very far from clear—so much so, that his French and Italian translators have made sad havoc of the passage [**129**]. And although Las Casas said of the book that it contained as many lies as it had pages, it is to be remembered that Oviedo was the Spanish Historiographer-Royal, and in this capacity would have access to all official records bearing on the voyages of Columbus. After Oviedo, we have Pedro de Medina (1555) and Pedro Nunes (1537). The former even denied the existence of declination, ascribing the supposed results to defective instruments or faulty observations [**130**]. The latter gives directions for finding the declination [**131**]. But neither mentions Columbus.

Thus, apart from the question whether Columbus did or did not discover the declination, three centuries elapsed during which, if we except Ulloa's translation of Fernando Columbus' *Historie* and the writers [**132**] who copied therefrom, the name of Christopher Columbus is never associated with the discovery of magnetic declination, and during which, as will be shown later, other claims were brought forward. Surprise has been expressed [**133**] that such should have been the case. But, apart from the merits of the Columbus claim, the explanation is not far to seek. To begin with, nothing seems to have been publicly known with regard to the observations made by Columbus until the issue of Ulloa's translation in 1571. By that time, other interests had been created; the question of the position of the agonic line had led to attempts at finding the longitude by magnetic methods; attention was drawn off to schemes of exploration and conquest; and, it might be held, Spain, as a land of scholarship and research, had begun to sink. Ulloa's translation had, probably, but a limited circulation, for it was not translated into French until 1681, nor into English until 1744, while it was only in 1748 that it was retranslated into its original Spanish. Gilbert's *De Magnete* appeared in 1600 and focussed enquiry into the wider aspects of the subject. The magnetic declination was now an acknowledged fact; its origin must have been regarded as one of many things imbedded in the distant past. These conditions or others of similar tendency apparently led to neglect of the early history of the science and the earlier records upon which it was based. It was not until Navarette found the Las Casas manuscripts that the name of Columbus was again brought into prominence.

The first distinct reference, apart from Ulloa's translation, to the observations is that by Formaleoni in 1783 [**134**], a few years before Navarette's discovery. He makes two statements of importance. The first is that it is wrong to ascribe the discovery of declination to George Hartmann in 1538, "for it had been known before him, and known for a long time." The second—which may possibly be a quotation from Ulloa's translation—contains the following: "In the history of voyages, I found express mention of the observations made by Columbus of the deviation of the needle; that in these new seas he found it to vary very much from that observed in the Mediterranean, which embarrassed him and was regarded by the Spaniards as a new phenomenon." The important point here is that Formaleoni does not ascribe the discovery of the declination to Columbus and refers to its value in the Mediterranean

as known before Columbus. Further, it is doubtful whether he ascribes the discovery of the space-variation of the declination to Columbus, for it is a moot point whether his phrase "by the Spaniards" is to be construed as meaning that other nations had previous knowledge of the phenomenon.

25—We have now to summarise the conclusions reached with regard to the claim advanced on behalf of Columbus, that he was the first to observe the magnetic declination, or at least that he discovered the space-variation of the declination. These claims have been considered on their own merits, without prejudice from the previous history of the matter. With reference to the first of these two questions, the following conclusions appear to be reasonably established by the available evidence:

(a) That the faulty steering of the ships on September 9, 1492, has no bearing on the question. In his transcription of the Las Casas manuscripts, Navarette made one serious mistake, after correction of which the whole matter appears in a simple light and unconnected with questions of declination.

(b) That it is almost entirely certain that an easterly declination had been observed in northwestern Europe before Columbus sailed on his first voyage. The proof is meanwhile inferred from the Columbian records themselves. It therefore follows that the magnetic declination was not discovered by Columbus.

With regard to the second question, the conclusion is:

(c) That the observations made by Columbus in his first westward voyage in 1492 are, in a rough manner, consistent with his having crossed the agonic line, but that he attributed the results to entirely erroneous causes, and thereby failed to recognise them as evidence of a general space-variation of magnetic declination. There are also slight indications that before this first voyage the fact that declination was not of equal amount at all places was known to several navigators.

26—In the literature of the present subject, reference is frequently made to the possibility of the magnetic declination having been discovered by John Cabot or by his son Sebastian Cabot. Neither left behind him any writing or other document in which this claim is definitely put forward and its general foundation is practically confined to statements made by third parties. These have now to be considered.

In dealing with this matter, certain dates have to be kept in view. The years of birth and death of both the Cabots are not exactly known, but it is probable [**135**] that the father was born not later than 1451, and the son before March 1474. John Cabot's first voyage of discovery, really inspired by the earlier enterprise of Columbus, was carried out in 1497, and his second voyage was in the following year. Whether Sebastian, who afterwards became the more famous man, actually accompanied his father on either of these voyages seems to be doubtful. For several years, little is heard of Sebastian, until in 1514 he entered the service of the Spanish Government, was appointed a pilot, and in 1518 became Pilot-Major to His Catholic Majesty. In this capacity, and as

a member of the Junta, he must have been closely acquainted with many of the results of the enterprise of Columbus, particularly in their bearing on oceanic navigation. There is, however, no direct evidence on this point. In 1544, he published his famous planisphere, on which he indicated the agonic line passing north and south in 25° west longitude [**136**]. In the following year, we find him engaged with others at Seville in examining and reporting on Pedro de Medina's treatise on navigation [**137**].

The earliest document connected with Sebastian Cabot and his possible discovery is to be found in the correspondence between the Senate of Venice and their ambassador, Contarini, at Valladolid. During an interview with the latter in 1522, Sebastian Cabot stated that he knew of a method by which the distance between two places, east and west, could be found by the compass, and that it had never been observed by any one else [**138**]. This communication to the ambassador, who forwarded it to the Senate, could have had no influence at the time, for it was hidden in the archives of the celebrated Council of Ten—a body eminently well qualified to keep its own secrets—and was unknown until 1864. Cabot's was probably an early form of the attempt to determine longitude from the declination, supposed known along a circle of latitude. The sixteenth century saw several attempts of the kind [**139**]. But Cabot's statement to the ambassador has no bearing on the question of priority, for the existence of declination had been proved long before 1522.

The first writer who advanced any express claim on behalf of Sebastian Cabot was Livio Sanuto. His book [**140**] was published in 1588, but was written before 1553, while Sebastian was still alive. Sanuto stated that a friend had informed him some years before—when, he does not say—that the magnetic needle does not always point to the geographical meridian of the observer; that Sebastian Cabot had discovered this fact and, in the presence of the friend referred to, had communicated it to the King of England, and that he also showed that the divergence between the two meridians was not the same at all places. This statement by Sanuto was accepted and given wide currency by several influential writers, among whom may be mentioned Gilbert [**141**], Kircher [**142**], and Fournier [**143**]. A similar statement was made by Fontenelle [**144**] in 1714, but, as pointed out by Harrisse [**145**] who has investigated the matter with his usual thoroughness, this was probably derived from an inscription on one of Cabot's maps. Another possible source for such statements was an inscription on Ruysch's *Mappamundi* of 1509. This inscription was placed on the map in a position about latitude 85° north and longitude 25° west and said that "*Hic compassus navium non tenet, nec naves qui ferrum tenent revertere valent*" [**146**]. This, of course, was only a reflection of the opinion, then widely held, that the directional property of the magnet was due to the presence, in the far north, of powerfully magnetic islands. Writers who based their accounts on this source may have been misled by the commentary on Ruysch's map by Marcus Beneventanus, which referred to discoveries made by the English in these regions, and may have connected them with one or other of Cabot's voyages under the English flag. Still later writers, for example, Lelewel [**147**], improve upon the matter by dating Cabot's discovery in 1497 but for this there is absolutely no evidence.

Sebastian Cabot cannot, however, be upheld as the discoverer, either of the declination or of its space-variation, and this for several reasons. First, and principally, the declination was known before his father's first voyage. Second, had Cabot deserved such honor, some at least of the writers on nautical matters of the time, who knew both the man and his achievements, would have mentioned his name in this connection. But these, including Oviedo [**148**], Pedro de Medina [**149**], Cortes [**150**], and Nunes [**151**], are silent. Lastly, at an important meeting of pilots held at Seville in 1536, at which Sebastian Cabot was most probably present in his capacity of Pilot-Major, a map showing declination, prepared by Alonzo de Santa Cruz, was exhibited [**152**]. Yet nothing was then advanced by or on behalf of Sebastian Cabot as an earlier discoverer of what was thus represented. Other names are connected with the study of such questions, but that of Cabot receives no mention.

27—During the sixteenth century, we have the earliest recorded values of the magnetic declination at many places over a wide area. These cannot be regarded as evidences of the origin of the conception of declination and, especially as they have an interest of their own in the history of the subject, they require separate and later treatment. We therefore conclude our investigation into all known or supposed origins with the examination of the claim to priority put forward on behalf of Sebastian Cabot. The way is therefore clear to draw such conclusions as the records would appear to warrant.

The discovery of the directional property of a suspended magnet was reached in an age which was but poorly equipped to apply accurate tests to such a property. Instruments for such purposes were very few and very crude. Add to this the fact that it was a time in which discussion tended towards the assignment of quality, rather than the determination of physical magnitude, and we need not be surprised that progress towards the second fundamental in terrestrial magnetism was uncertain and slow. But the recognition of magnetic declination was only a matter of time, depending as it did upon improvement in instrumental means and the consequent increase in accuracy of observation.

From the earliest records quoted, one derives the conclusion that, long before the regular observation of declination as an accepted fact, there must have been a vague impression that the magnet did not coincide in direction with the geographical meridian. Even in 1266, when Roger Bacon wrote, the possibility of its pointing in other directions had been mooted and it is difficult to conceive of Bacon writing as he did without some observational data at his disposal. It is legitimate—without adopting the facile process of raising conjecture to the level of historical fact—to suppose that cases would occur irregularly in which attention would be directed to the fact of such divergence between the two meridians. But these would not form the subject of record, although they might be common knowledge among those who had actual contact with the matter—that is, among sailors and makers of compasses, sundials, maps, and charts.

It is here, then, that the beginnings of the conception of magnetic declination are to be found—among those whose business in life was to take cognisance of such matters and deal with them as actual affairs. Unfortunately for the historian of science there is no record of the process and we are only permitted to know its outcome. This took the

practical form of making an allowance for the declination in the construction of sun-dials and nautical compasses. The date at which this adjustment was first effected cannot be fixed with certainty. As the records stand, the earliest indication is given by the Nuremberg sun-dials dating from about 1450. The first report of the Flemish compass with its adjusted needle is nearly half a century later, but the fact that it then appears in fairly general use would argue that it had been employed for many years. Lastly, the records do not justify the association of any particular name with either the first recognition of declination or with the practical measures adopted to allow for it in sun-dials or compasses. None of the claims put forward, whether on behalf of the Chinese, or of Peregrinus, Christopher Columbus, or Sebastian Cabot can be substantiated.

The general conclusion reached, therefore, may be stated as follows. Within a century after the first mention in literature of the nautical compass, we find allusions in the writings of Roger Bacon to the fact that the direction of the magnetic needle does not coincide with the geographical meridian. When, where, and by whom this was first observed is now unknown. At first, this deviation was ascribed to irregularities in the process of magnetisation of the compass-needle, or to faulty methods of observation. But gradually it came to be recognised as a general and world-wide phenomenon and it is probable, though there is no extant record to establish the fact, that this stage was reached in the earlier years of the fifteenth century. Very soon thereafter and certainly not later than 1450, the makers of sun-dials in Germany introduced improvements in their instruments in order to avoid the effects of deviation of the needle. Possibly about the same time, though more probably later, the compass-makers of Holland adjusted their compass needles with the same object. The Mediterranean navigators continued to use the compass without this adjustment. Finally, no original observation, discovery, or instrumental improvement, as made or effected down to the end of the historical period concerned, can be definitely or exclusively associated with the name of any particular person.

Bibliographical Notes and References

[References which have not been examined and verified are marked by an asterisk.]

[1] In the case of the compass referred to by the Persian Awfi (Chapter I, p. 119), it would seem to have been regarded as something new. But this may have been due to the writer's limited acquaintance with nautical matters.

[2] Wylie, *Chinese researches*, Shanghai, 1897, Part III, 155.

[3] *Terr. Mag.*, XXXVII (1932), 109-110. Wylie's statements have been repeated by Chu-Co-Ching, *Geog. Rev.*, V (1918), 137-138, but without giving any further information.

[4] Hirth, *Ancient history of China*, New York, 1911; Chronological summary, under 700 A. D.

[5] Hashimoto, *Memoirs of the Research Department of the Toyo Bunko*, Tokyo, 1926, No. I, p. 85.

[6] See [5], p. 85.

[7] See [4], p. 132.

[8] **Mung-khi-pu-py-than. Ch. III.*

[9] Klaproth, *Lettre à M. le Baron A. de Humboldt sur l'invention de la boussole*, Paris, 1834, p. 68, quotes from the *Pen-thsao-yan-i*, compiled 1117 A. D. The same source was used by Gaubil, *Observations mathématiques, astronomiques, géographiques,*

chronologiques, et physiques, tirées des anciens livres chinois, ed. by Souchet, Paris 1729, 3 vols; Hager, *Memoria sulla bussola orientale*, Pavia 1809 and 1810; Biot, *C. R. Acad. sci.*, XIX, 822-829. The passage also appeared in the twelfth century dictionary *Poei-wen-yun-fou* and in the medical and zoological work, entitled *Pen-thsao-kung-muh*, completed about 1580. Bertelli, *Mem. Acc. Nuovi Lincei*, IX, Part I, reports it as occurring in the great Sino-Japanese encyclopedia *Wa-kau-san-sai-dzu-ye*, Bk. XVI, fol. 19. Translations by different commentators have not always been in agreement. See Bertelli, *Bull. Soc. geogr. ital.*, III, and De Moidrey, *Terr. Mag.*, IX (1904), 29.

[10] Le Comte, *Nouveaux mémoires sur l'état présent de la Chine*, Paris 1696, I, lettre VIII; in the English edition, London, 1699, p. 229.

[11] Amiot, *Mémoires concernant le Chinois*, Paris, 1788, 13 vols., IX, 2.

[12] Gaubil, *Description de ville de Peking*, Paris, 1763, p. 8.

[13] See [**5**], p. 88.

[14] Fr. Rogeri Bacon, *Opera quaedam hactenus inedita*, ed. by Brewer, vol. I, Rolls Series, 15, p. 383-384. The passage is as follows: "Et hoc est miraculum naturae in parte notum; scilicet, quod ferrum sequitur partem magnetis quae tetigit ipsum, et alteram partem fugit ejusdem magnetis. Et convertit se post motum ad partem coeli conformem parti magnetis, quae ferrum tetigit. Nam pro certo quatuor partes mundi distinguuntur in magnete, scilicet oriens, occidens, septentrio, et meridies; et possunt per experientiam cognosci, secundum quod bene exformiter ad quam partem coeli quaelibet pars tendit. Et nunc si a parte septentrionali magnetis tangatur ferrum sequetur illam partem qualitercumque meatur; scilicet sursum aut retrorsum, dextrorsum, sinistrorsum; et secundum omneno differentiam positionis. Et in tantum rapitur, quod si ferrum ponatur in vase pleno aquae, et manus ponatur sub vase, tacta pars demergit se in aqua in directum magnetis. Et si deferatur undique magnes extra nos, ferrum super partem tactam erectam currit in directum cujuslibet loci, ad quem defertur magnes. Et si ima pars magnetis objiciatur parti ferri tactae fugaret eam sicut inimicam; sicut agnus lupum (MS, *vapum*). Et ablato magnete pars tacta dirigit se ad locum coeli similem parti magnetis.

Vulgus philosophantium nexit causam experientiae vulgatae in hac parte, et credit quod stella Nautica (MS. *Naucita*) facit ad hoc. Sed stella non facit ad hoc sed pars coeli. Et ita bene operantur tres aliae mundi partes; scilicet meridies, oriens, et occidens, sicut septentrio. Similiter non considerant quod quatuor imae partes mundi distinguantur in magnete. Sed tot attribuunt uni parti, quae cum stella convenit Nautica (MS. *Naucita*) in naturali proprietate. Et aliae sunt hujusmodi experientiae et meliores non de ferro solum et magnete, sed de auro, et omnibus metallis respectu diversarum specierum magnetis, sicut docetur in libro *De Proprietatibus*. Et non solum in his sed in omnibus rebus mundi necesse est quod partes quatuor signentur, secundum quatuor partes coeli, et maxime in his rebus, quae fixum habent locum, ut in rebus inanimatis et plantis; non habent continue partem determinatam ad oriens, et aliam ad occidens, et ceteras duas ad septentrionem et meridiem, et continuas et perpetuas recipiant influentias a partibus coeli; respectu quarum habent situm quod possumus experiri in rebus infinitis."

[15] *Terr. Mag.*, XXXVII (1932), 126-127, and notes [**265**], [**266**].

[16] See [**15**], notes [**242**], [**243**]. By an unfortunate misprint, the date of the Peregrinus letter was given as 1209, instead of 1269, in Chapter I, [**15**] p. 125.

[17] Thévenot, *Recueil des voyages*. Paris, 1681, p. 29; also *Journal des Scavans*, Amsterdam, 1688, T. 15, p. 561.

[18] For example, Van Swinden, *Mém. de mathem. et de phys. présentés à l'Acad. Roy. des Sci.*, VIII, 5-6, note; Gehler, *Physikalisches Wörterbuch*, Leipsic, 1787, I, 16; also in the 1825 edition, IA, 136; Barlow, *Phil. Trans. R. Soc.*, 1833, II, 670.

[19] Cavallo, *Treatise on magnetism*, 3rd ed. London, 1800, 299-320. The first edition, 1787, does not refer to "Adsiger."

[20] Wenckebach, Mulder's **Natur en Scheikundig Archief*, Rotterdam, 1836, 275-297; French trans. by Hooiberg in *Annali di Matem.*, VII, 159-168.

[21] Following Wenckebach, Libri, *Histoire des sciences mathématiques en Italie*, Paris, 1838, I, 383, II, 70-72, with notes, dealt with the matter at some length, giving translation (I, 487) of the genuine *Epistola* from the copy in the Bibliothèque Nationale, Paris (MS. Latin, No. 7378A). He acknowledged the value of Wenckebach's researches. About the same time, Humboldt took a hand in the business, but only succeeded in darkening counsel. In his *Examen critique de l'histoire de la géographie du Nouveau*

Continent, Paris, 1837, I, 240, he says "En Europe, cette déclinaison avait déjà été trouvée par Peregrini en 1269." But in vol. III, 30, he contradicts himself by referring to this as "une pretendue observation." He then proceeds to quote Libri's opinion on the Leyden manuscript, without acknowledging Wenckebach, whose paper he had, apparently, never seen. He represents Libri as saying that the passage relating to the declination is *not* in the Leyden manuscript. Libri did not say this. What he did say was, that the passage was not in the genuine copies of the Peregrinus letter.

It is interesting to note that, shortly before this, Humboldt had been criticising Columbus as being the victim of disordered ideas, of which his writings carry the imprint! !

[**22**] Bertelli; see notes [**103**, *a*, *d*, *h*], of Chapter I.

[**23**] It would be tedious and unprofitable to add a list of writers who have accepted or reproduced Thévenot's original assertion. But the reader who wishes examples of an error repeated half a century and more after its exposure can find them in Justin Winsor's *Christopher Columbus*, London, 1890, p. 199 in Hutchinson's *Advanced textbook of electricity and magnetism*, London, 1917, I, p. 4, and—*quandoque bonus dormitat Homerus*—in Poynting and Thomson's *Electricity and magnetism*, London, 1914, p. 169.

That this interpolation in the Leyden manuscript should have remained so long without notice was most probably due to the limited circulation of the journal in which Wenckebach's paper first appeared. For example, Brewster, writing in 1857 (*Encyclopedia Britannica*, 8th ed., XIV, 2) does not refer to it, although it would have cleared up what seemed to him doubtful.

[**24**] Winter, *Ann. Hydrogr.*, LXIII (1935), 352-363.

[**25**] Thorndike, *History of magic and experimental science*, Washington, 1934, vol. III, 499, 501. Also contains details regarding the life and writings of Henry of Hesse. The *Contra coniunctionistas* is in British Museum manuscripts, Sloane, 2156, the passage being in I, 15. The context is obscure and appears to have little or no bearing on the subject, except that it might have been introduced as an example illustrative of principles which are put forward with regard to matters of a totally different kind. Professor Thorndike informs me that the text of *Contra coniunctionistas* has been edited by Pruckner in his *Studien zu den Astrologischen Schriften des Heinrich von Langenstein*, Berlin and Leipsic, 1933, 139-206.

It is stated in the text that the contribution to the subject by Henry of Hesse is the only one of its kind known in the fourteenth century. There is, however, another possible reference which must be mentioned. In his *Parlement of Foules*, line 117, Chaucer refers to the planet Venus "as wisly (surely) as I see thee in the north-northwest." That the poet should have supposed the planet to have been visible in this direction from, say, London, is surprising. Skeat's note on the passage (*Works of Geoffrey Chaucer*, London 1894, Vol. I, p. 509) is not very illuminating. Professor Hugo Lange and Dr. A. Nippoldt are of opinion that the direction is correctly given if we suppose that Chaucer was using an azimuth *taken from a compass-direction*, and that the magnetic declination at London in 1380 was 23½° west. That Chaucer was acquainted with the compass, and even used it for such purposes, is perfectly possible. That he was also aware of the magnetic declination, especially when of large amount, is also possible and even probable. But it is not an inevitable deduction from the passage and I do not gather that the writers mentioned put it forward as such. The whole matter seems to depend rather upon the view which may be taken as to the nature of the secular change in declination, and should therefore be dealt with in connection with that part of the subject. See Lange, *Anglia, Zeitschrift für englische Philologie*, Bd. XLVIII, Heft 3/4, and *Forschungen und Fortschritte*, 20 April, 1935. Professor Lange has very kindly sent me (July 27, 1936) a paper, in typescript, giving his own and Dr. Nippoldt's views on the matter, but I am not aware of this having been published as yet.

[**26**] Toaldo, *Saggi di studi veneti*, Venice 1782, p. 61. Bianco's map has been reproduced by Peschel, *Facsimile dell'atlante di Andrea Bianco*, Venice, 1869, German ed. of same year. Also by Mayer, *Die Entwickelung der Seekarten*, Vienna, 1877.

[**27**] Formaleoni, *Saggi sulla nautica antica dei Veneziani*, Venice, 1783.

[**28**] Humboldt, *Cosmos*, English trans., London, 1849, IV, 53.

[**29**] Libri, [**21**], II, 72.

[**30**] Mottelay, *Bibliographical history of electricity and magnetism*, London, 1922, p. 62.

[**31**] Bauer, *Principal facts of the Earth's magnetism*, U. S. Coast Geod. Surv., Washington, 1909. His conclusions were drawn rather from the map itself than from the attached diagram.

[**32**] Bertelli, *Bull. bibliogr. st. sci. mat. fis.*, I, 411.

[**33**] Bertelli, *Raccolta di documenti e studi pubblicata della Reale Commissione Columbiana nel quarto centenario della scoperta di America*, Rome, 1892. Part IV, 88.

[**34**] Heathcote, (a) *Sci. Prog.*, XXVII (1932), 89; (b) *Annals of Science*, I (1936). Apart from other points of value, these papers give many references to early charts, and their interpretation by Gelcich, Kretschner, Peschel, and Breusing.

[**35**] Libri, [**21**] II, 71. Libri also refers to a German map in the Paris Bibliothèque Nationale, which shows the declination, but no particulars are given.

[**36**] MSS. Italiens, histoire et géographique, No. 42. Bertelli [**32**], Tav. IV, has reproduced the compass-card forming part of the map.

[**37**] Molini, *Documenti di storia italiana*, Florence, 1836, I, lxix.

[**38**] Hellmann, *Zs. Ges. Erdk., Berlin*, XXXII, 112-136.

[**39**] Wolkenhauer, *Mitt. Geogr. Ges., München*, I, 161-260.

[**40**] Hellmann quotes from (*a*) Doppelmayer, *Historische Nachricht von den Nürnbergischen Mathematicis und Künstlern*, Nuremberg 1730; (*b*) Grimm's *German Dictionary*, Leipsic, 1873, V, 1685; (*c*) Sebastian Munster, *Horologiographia*, Basle, 1533, p. 7; but chiefly relies on (*d*) a passage in a letter addressed to Prince Albrecht of Prussia by George Hartmann, dated March 4, 1544. Reference may be made to the *Oxford English Dictionary* for different meanings of the word "compass."

Hartmann's letter, which is of considerable importance in the history of terrestrial magnetism, was found in the archives of Königsberg, and was first published by Voigt in Raumer's **Historisches Taschenbuch*, vol. II; later by Moser in *Repertorium der Physik*, vol. II; again by Voigt in his *Briefwechsel der berühmtesten Gelehrten des Zeitalters der Reformation mit Hertzog Albrecht von Preussen*, Königsberg, 1841; and lastly by Hellmann in his *Neudrucke von Schriften und Karten über Meteorologie und Erdmagnetismus*, Berlin, 1898, No. 10. In this letter, Hartmann refers to observations of magnetic declination made while he was in Rome, and their date can be almost certainly fixed (see *a*, above, p. 57) as in the year 1510. For errors arising from ascribing the observations to the year of the letter, see Hellmann [**38**], p. 128, and Wolkenhauer [**39**], p. 183.

[**41**] I quote from Hellmann [**38**], p. 113, not having seen either document. Nor have I been able to ascertain their present location.

[**42**] A complete list of the works of Regiomontanus will be found in Ersch and Gruber's *Cyclopedia*, vol. III. The instruments used, and observations made by him in Nuremberg are detailed in a posthumous work, **Scripta clarissimi mathematici Joh. Regiomontani*, Nuremberg, 1544. Details regarding his life and work may be gathered from Gassendi's biography, *Tychonis Brahei equitis Dani astronomorum coryphaei vita*, Paris, 1659.

Thorndike, *Science and thought in the XV century*, New York, 1929, ch. VIII (with some valuable references), is of opinion with regard to Peuerbach and Regiomontanus, that "their importance has been exaggerated at the expense of the preceding period and their own contemporaries." This criticism is intended to apply to their astronomical and mathematical work, and whether well-founded or not—a point upon which I am not qualified to offer an opinion—has no bearing on that aspect of their work with which we have to deal here.

[**43**] See [**40**].

[**44**] See Doppelmayer [**40**, *a*].

[**45**] Le Monnier, *Hist. Acad. sci.*, Paris, 1771, p. 29.

[**46**] In Hellmann's original paper [**38**], this is given as 10°, but was corrected in the translation which appeared in *Terr. Mag.*, IV, 79. With regard to the value 7°, see Fritsche, *Die Elemente des Erdmagnetismus und ihre saecularen Aenderungen während des Zeitraumes 1550-1915*, St. Petersburg, 1900.

[**47**] See [**39**], 257.

[**48**] Mayer, *Mitt. aus dem Gebiete des Seewesens*, 1878, Bd. 7, p. 331. See Spitzer, *La Collection Spitzer*, Paris, 1890. This collection has since been dispersed by auction, and the present whereabouts of the instruments appears to be unknown.

[**49**] The sun-dial of 1451 has been separately described by Hellmann in *Met. Zs.*, XXIII, 145-149. He paid particular attention to the question as to whether the

mark indicating the magnetic north had been made at the time of construction of the instrument. This matter had been raised by some critics, who suggested that it might have been added later. But Hellmann was perfectly satisfied that the mark had been made on the instrument as originally constructed.

[**50**] Wolkenhauer [**39**], 193-199. Fuller details are given in his later paper, *Deutsche geographische Blätter*, XXVI, 120-138. The maps have been republished by Wolkenhauer in *Erhard Etzlaubs Reisekarte durch Deutschland 1501*, Berlin, 1919, which contains many references to the literature of the subject. Etzlaub's year of birth is unknown, but is believed to be about 1460. In 1484 he was enrolled as a burgher of Nuremberg, and died there in 1533.

[**51**] *Historie del Signor Don Fernando Colombo nelle quali s'ha particolare e vera relatione della vita e de' fatti dell' Ammiraglio D. Christoforo Colombo suo padre. Tradotte nell' Italiana dal S. Alfonso Ulloa.* Venice 1571. Second edition, Milan 1614. The *French edition, Paris, 1681, is said by Thacher to have been badly translated. The English translation, included in Churchill's *Voyages and travels*, London, 1744, II, 479-604, contains several errors, some of which are referred to later. A retranslation into Spanish was given by Barcia in his *Historiadores primitivos de las Indias Occidentales*, Madrid, 1748, Italian edition, by Dulau, London, 1867. The best modern edition is that of Rinaldo Caddeo, Milan, 1930, 2 vols. It giyes in the Introduction a life of Fernando Columbus (xii-xvii), deals with the question of authenticity (xix-xl), its truth and authority (xli-lviii), a list of editions (lix-lxviii), a bibliography of the *Historie* (lxxi-lxxv), and a list of works relating to Christopher and Fernando Columbus (lxxvi-lxxxvii). The edition of the *Historie* follows, and is fully annotated.

[**52**] The Las Casas MS of the *Journal* of Columbus was first published by Navarette in his *Colección de los viajes y descubrimientos que hicieron por mar los Españoles desde fines del siglo XV.* Madrid, 1825, 2 vols. I, 1-166.

Navarette's edition, with or without corrections, has been reproduced several times. (*a*) *Personal narrative of the first voyage of Columbus to America, from a manuscript recently discovered in Spain*, Trans. by S. Kettell, Boston, 1827. In some respects, this is incomplete, and it was scarcely accurate to announce the discovery as "recent" when it had been known to scholars for nearly forty years. (*b*) *Relations des quatre voyages entrepris par Christophe Colomb*, Trans. by Verneuil and de la Roquette, Paris, 1828, 3 vols. II, 1-345. (*c*) Italian translations by *Marmocchi, 1840, and *Torre, 1864. (*d*) Varnhagen, *La verdadera Guanihani*, Santiago de Chili, 1885. (*e*) Los Rios, *La parte de los Montaneros en el descubrimiento de America*, Santander 1892. (*f*) The best edition, with valuable notes and references, is that by Lollis in the monumental Italian publication, [**33**], vol. I, 1-119. (*g*) Markham, *The journal of Christopher Columbus during his first voyage*, 1492-93, Hakluyt Soc., London, 1893. (*h*) Thacher, in his *Christopher Columbus*, New York, 1903, 3 vols., I, 512-570. (*i*) Brooks, *Christopher Columbus, his first voyage to America*, London, 1925; this is a close copy, even to the notes, of (*a*) above. The latest version is Duff's *The truth about Columbus*, London, 1936. The author states in his preface that he has "relied upon original sources," and that he "found that without exception English translations of the *Journal*, letters and documents, were either incredibly inaccurate or incredibly wooden, thus providing at source a basis for misinterpretation or misrepresentation." The original sources of the *Journal* are the two Las Casas manuscripts, and neither Navarette's, nor any other, edition or version of them. Had the author relied on this original, he would have avoided adding to the list of incredible inaccuracies, for it will be found that under September 9 and 13 he repeats Navarette's mistakes in transcription.

Las Casas gave, with some differences in detail, a copy of his edition of the *Journal* in his *Historia de las Indias*, first published at Madrid, 1875, 5 vols., I, 261-469. This was used, in abbreviated form, by Herrera in his *Historia general de los hechos de los Castellanos en las islas i tierra firme del Mar Oceano*, Madrid, 1730, 3 vols., Dec. I, lib. I, c. IX-XX; lib. II, c. I-III.

[**53**] For discussions as to the birthplace of Columbus, see Washington Irving, *History of the life and voyages of Christopher Columbus*, Paris, 1828; Harrisse, *Christophe Colomb, son origine, sa vie, ses voyages, sa famille, et ses descendants*, Paris, 1884; Thacher [**52**, *h*], I, 230-263; Vignaud, *Etudes critiques sur la vie de Colomb*, Paris, 1905; *Christopher Columbus: Documents and proofs of his Genoese origin, Published by the City of Genoa*, Genoa, 1932.

[**54**] As to date, see authorities quoted in [**52**], especially Thacher, I, 264-285.

[**55**] The controversy on this point, the social position of the Columbus family, began by Bishop Agostino Giustiniano asserting in his *Psalterium Hebraeum, Graecum*,

Arabicum, et Chaldaicum, Genoa, 1516 (note to Psalm XIX), that Columbus was of common parentage, *ortus vilibus parentibus*. This was rather vehemently contradicted by Fernando Columbus in his *Historie* [**51**], ch. II. Further discussion by Thacher [**52**, *h*], Vignaud [**53**], and other critics has settled the matter. See also [**75**].

[**56**] As may be conclusively proved by a comparison of the earlier chapters of the *Historie* [**51**] with those of the *Historia* [**52**], the two authorities are not really independent. The conclusion under reference is only inferential, but is reached after consideration of all the relevant evidence. See the publication of the city of Genoa [**53**], p. xx. Markham, *Life of Christopher Columbus*, London, 1892, Ch. I, note 3, gives the best reasons for rejection of the statement by Fernando Columbus.

[**57**] Markham [**56**], Ch. I, note 3; see also references quoted by Jane, *Select documents illustrating the four voyages of Columbus*, London, 1930, Introduction, xxxvii.

[**58**] The sea-fight referred to took place on August 22, 1485; see Markham [**56**], p. 16, note.

[**59**] The best summary on this point will be found in Jane [**57**] Intr. xxxiii-xxxvi. Thacher [**52**, *h*], and Markham [**56**] formed a higher estimate of the educational attainments of Columbus than appears to be warranted. For the opposite view, see Vignaud [**53**] and Harrisse [**53**].

[**60**] See Jane [**57**] xxxvi.

[**61**] See Jane [**57**] xxxvi. Harrisse [**53**] points out that of all the writings we have of Columbus, there is none in Italian. When he wrote to the Pope, he used neither Latin, the usual medium, nor Italian, his mother-tongue, but Spanish.

[**62**] This is abundantly shown in his letter to the Spanish sovereigns, written from Haiti, October 18, 1498; the letter is printed in *Select documents* [**57**], II.

[**63**] See *Select documents* [**57**], II, Intr. lxxxi-lxxxiii.

[**64**] For example, Belloy, *Christophe Colomb et la découverte du Nouveau Monde*, Paris, 1865; Roselly de Lorgues, *L'ambassadeur de Dieu et le Pape Pie XI*, Paris, 1874, and his **Christophe Colomb*, Paris, 1856.

[**65**] Goodrich, **History of the character and achievements of the so-called Christopher Columbus*, New York, 1874.

[**66**] For example, Fernando Columbus, *Historie* [**51**], Ch. II. "Io non sono il primo Ammiraglio della mia famiglia." Jane [**57**] xx, points out that this statement is given by Fernando Columbus as coming from the letter to the nurse of Prince Juan; but the letter, as preserved, contains no passage of the kind.

[**67**] The story told by Columbus, and repeated by his son, of his having altered the compass in order to delude his crew, is entirely improbable.

[**68**] For example, see his *Journal* under September 9, 1492, when he entered the day's run as less than the actual. Also note by Jane, *Voyages of Christopher Columbus*, London, 1930, p. 331.

[**69**] See Jane [**57**], and [**68**] 58-60, where he deals with the reliability of the *Journal*. For a vigorous, yet temperate, expression of the need for reserve in accepting the statements by, or accredited to, Columbus, see the letter of Vignaud, in Filson Young's *Christopher Columbus and the New World of his discovery*, London, 1906, II, 373-380.

[**70**] Bertelli [**52**], (*f*), Part IV, II, p. 37, note, states that Fernando accompanied his father on the voyage to America in 1496. This is incorrect. No voyage was *begun* in 1496. The second voyage ended in June, 1496.

[**71**] See *Catalogue of the library of Ferdinand Columbus: Facsimile of a manuscript in Columbine Library, Seville*, by A. M. Huntington, New York, 1905.

[**72**] The earliest original source of information regarding the life and work of Las Casas is Remesal, *Historia de la Provincia de S. Vincent de Chyapa*, Madrid, 1619. A useful summary is given by Helps, *Life of Las Casas*, London, 1868. See also Thacher [**52**], (*h*), I, 113-159.

[**73**] *Historia de las Indias, escrita por Fray Bartolomé de Las Casas, Obispo de Chiapa*, Madrid, 1875, 5 vols.

[**74**] See [**51**].

[**75**] Harrisse, *Fernand Colombo, sa vie, ses oeuvres*, Paris, 1872. The grounds upon which Harrisse assailed the genuineness of Fernando's *Historie* are of interest. To begin with, Ulloa's translation has a dedication by Moleto to the Italian patrician Fornari. According to this dedication, the manuscript of the *Historie* was given to Fornari by Don Luigi, grandson of Columbus. Fornari handed it to Giambattista

de Marini, who took it to Venice and arranged for its translation into Italian by Ulloa. Now in writing an introduction to the Italian *Codice Diplomatico Colombo-Americano*, Genoa, 1823 (English ed., London, 1823), Spotorno stated, p. lxii, that Don Luigi, "persona di vita dissoluta," brought the manuscript to Genoa in 1568. Harrisse begins by pointing out that Don Luigi was arrested at Valladolid in 1558 on a charge of polygamy, was tried in 1563, and was exiled to Morocco until 1572. He could not, therefore, have been in Genoa in 1568. Secondly Martini was dead before 1567. Hence Spotorno's statement is materially impossible. Thirdly, although Fernando Columbus bequeathed his library to Don Luigi, the latter never took possession of it. The library was under seal in the house of Fernando from his death in 1539 until 1544. From 1544 to 1552, it was in charge of the monks of St. Paul's Convent, Seville, and from the latter year onwards it was in the Cathedral of Seville. Assuming that the manuscript was in the library, Don Luigi could never have had it in his possession. But beyond this, there is grave doubt as to whether the library contained the manuscript of the *Historie*. Fernando prepared several detailed catalogues of his library, but none of these mentions it. For instance, there is no entry of the kind in the facsimile printed by Huntington [**71**]. Nor is there any mention of it by any contemporary. None of the 450 works catalogued in Harrisse's *Bibliotheca Americana Vetustissima*, New York, 1866-72, refers to it. The earliest reference of a reliable kind is to Ulloa's translation and not to any original thereof. Harrisse ventures the hypothesis that the *Historie* was really written by Fernand Perez de Oliva, whose manuscript certainly existed in the Library of Fernando Columbus. Another interesting point regarding the *Historie* and its authorship is its reference to Bishop Agostino, who is mentioned in Chapter II as the author of a "chronicle." This unfortunate prelate (he was drowned at sea) wrote two works. The first, his Psalterium [**55**], was published in 1516 and contained some reflections on the parentage of Columbus. The second was his *Castigatissimi annali della eccelsa et illustrissima Republica di Genoa, da fideli et approvati scrittori*, published at Genoa, in March 1537, and in which were repeated the statements made in the *Psalterium*. The question is, to which does the *Historie* refer? The term "chronicle" could scarcely apply to the *Psalterium*, but would be accurately descriptive of the *Annali*. But if to the latter, the difficulty arises that Fernando Columbus was ill for a long time before his death in 1539 and, if able for any work at all, was engaged in other matters. Hence either the reference to Agostino's work must be an interpolation or the *Historie* must have been written after the death of Fernando Columbus.

[**76**] D'Avezac, *Bull. soc. géog.*, *Paris*, 1872, 1873. Harrisse's answer is in same Journal, 1874.

[**77**] Perogallo, *L'authenticità della historie di Fernand Colomb*, Genoa, 1884. *Duro, *R. Acad. de la Hist.*, *Mem.* X, Madrid, 1896.

[**78**] See [**52**] (b), I, 143.

[**79**] See [**52**].

[**80**] This point is discussed by Vignaud, *Histoire critique de la grande entreprise de Christophe Colomb*, 2 vols., Paris, 1911, I, 18-20. Also by Jane [**68**], Introd. 59-60.

[**81**] See [**52**] (*h*), I, 513. Thacher also states, p. 512, that Las Casas "had in his possession, among many other of Christopher Columbus' papers, his original holograph Journal." A simple statement this, but it comes perilously near to that method in historical writing so severely denounced by F. C. Baur, namely, drawing conclusions regarding the uncertain from the unknown (*Life and works of St. Paul*, Part I, ch. VII). Evidence in support is entirely lacking.

[**82**] Markham [**52**], (*g*). Introd. p. v.

[**83**] Filson Young [**69**]. Lord Dunraven contributed a note, I, 291-322, on the navigation of Columbus. He states that, according to the *Journal*, Columbus manipulated the compass so as to make it point to the Pole Star. There is no passage in the *Journal* which bears this out. By some writers it has been suspected that he may have done so, but there is no proof. The idea may have its origin in the story told by Columbus himself, and referred to in [**67**].

[**84**] Navarette [**52**], (*b*).

[**85**] This sentence was drafted early in 1936. In view of the present unhappy state of affairs, it would be more accurate to say "formerly" instead of "now."

[**86**] For permission to obtain photostat copies of the relative portions of the original Las Casas manuscripts, I have to thank the Director of the National Library, Madrid, and also Mr. A. R. Hinks, Secretary, Royal Geographical Society, London, through whose good offices these copies were obtained. For a careful scrutiny of these

records, and for notes on their translation, I am much indebted to Mr. L. B. Walton, Lecturer in Spanish, University of Edinburgh.

[**87**] The original, Plate I, gives "norueste." Navarette gave "nordeste," which reading was accepted by those who had not examined the original, or a facsimile thereof. It also had a decisive influence on most discussions of the subject. The Italian *Raccolta* edition [**52**] (*f*) gives the correct reading, but strange to say, Bertelli, in the same publication, adopted Navarette's incorrect reading.

[**88**] The original, Plate II, gives "nordesteaban." The *Raccolta* edition gives the same, and notes Navarette's reading as a variant.

[**89**] Reproduction of original in Plate III.

[**90**] Navarette also gave "noruestean," whereas in the parallel passage in Las Casas' *Historia*, p. 281, we have "nordesteaban."

[**91**] Reproduction of original in Plate IV.

[**92**] See [**51**].

[**93**] Churchill's translation [**51**], p. 524, of this passage contains three errors: "Northwestward" in the first and third sentences is translated "northeast," and "invisible" is put as "visible."

[**94**] Copied from original Spanish and English translation given in *Select documents* [**57**], II, 56, which also gives details as to the provenance of the letter.

[**95**] These speculations regarding a protuberant portion of the oceanic surface were current in the times of Ristoro d'Arezzo in 1282, and of Paul of Venice about 1420. But it is highly improbable that Columbus was acquainted with either work.

[**96**] For remarks on the cosmographical speculations of Columbus as contained in this letter, see Jane [**57**].

[**97**] The earliest reference, after that of Fernando Columbus, to the practice of adjusting the needle under the compass-card, as in the Flemish compass, is that by Norman, *The newe attractive*, London, 1581 (reprinted in Hellmann's *Neudrucke* [**40**], No. 10). In Ch. X, he refers to different amounts of declination for which the adjustment is made. As an interesting indication of the accuracy aimed at, in Norman's time, in laying courses at sea, he recommends that the needle be set at half a point eastwards, as the maximum error will then be only a quarter point. A fuller description of these Flemish compasses is given by *Barentz, *Description de la Mer Méditerranée*, La Haye, 1599. The principal passage is given, in English, by Heathcote [**34**], p. 92. In Barentz's time, the Flemish compasses allowed for a declination of 6° east. Gilbert, *De Magnete*, London, 1600, Bk. IV, Ch. viii, also refers to the matter, and gives details as to the different declinations for which allowance was made. Gellibrand, *Discourse mathematicall on the variation of the magnetic needle*, London, 1635, p. 5, condemns the use of compasses adjusted in this manner, "considering the variation is perpetually variable, according to the shipp's motion."

[**98**] See the letter of Columbus, in passages *J*, *K*.

[**99**] For these details, I am indebted to Prof. R. A. Sampson, Astronomer-Royal for Scotland.

[**100**] Bertelli [**52**], (*f*), Part IV.

[**101**] Wolkenhauer, *Mitt. Geogr. Ges., München*, I, Heft 2.

[**102**] Errera, *Sulla scoperta della declinazione magnetica e sulla storia della bussola nautica nei secoli XV-XVI*, in *Riv. fis. mat. sc. nat.*, Pavia, 1907, 85.

[**103**] Magnaghi, *Boll. Soc. geogr. ital.*, Ser. IV, vol. x, 595-641.

[**104**] Bertelli [**52**], (*f*), Part IV.

[**105**] De Castro, *Roteiro de Lisbon a Goa por De Joao de Castro*, Ed. by Corvo, Lisbon, 1882.

[**106**] Schott, *U. S. Coast and Geodetic Survey report for 1880*, p. 416.

[**107**] See [**103**].

[**108**] See [**83**].

[**109**] See [**52**].

[**110**] See [**52**].

[**111**] See [**52**].

[**112**] See [**52**].

[**113**] See [**52**].

[114] See [**21**].

[115] See [**52**], (*f*), Part IV.

[116] Fox, *U. S. Coast and Geodetic Survey report for 1880*, p. 405, states that compass-sights only came into use in the following century.

[117] There is some doubt as to the value of the league used by Columbus. See Fox [**116**], p. 401.

[118] The view presented in this paragraph was first put forward by D'Avezac, *Bull. soc. geog., Paris*, Series IV, XIX, 356; also *C. R. Acad. sci.*, LXX, 1080.

[119] Heathcote [**34**] gives a different explanation, with which I am unable to agree.

[120] For example, Pedro de Medina, *Arte de navegar*, Valladolid, 1545, lib. vi. Many years later than Columbus, a belief was current that different degrees of magnetisation of the compass-needle produced different amounts of deviation from the geographical meridian. This was finally disposed of by Sellers, *Phil. Trans. R. Soc.*, 1666, p. 473.

[121] See [**52**], (*f*), Part IV.

[122] The letter is printed by Harrisse [**75**], 470-471. Bertelli's notes [**52**], (*f*), Part IV, ch. II, p. 19, on the letter should be consulted along with it.

[123] See [**52**], (*f*), Part IV.

[124] Bertelli's reference is to *Pubblicata da Guglielmo Brenna*, Florence, 1886, p. 5, but I have not had an opportunity of verifying this. The passage is as follows: "Maraviglia me fe assai el variare della bussola, non solamente la nostra, ma di tutte l'altre dell'armata, che la fiamma della tramontana, passando noi di Ginea, convincio a inclinare, secondo el parere de piloti, una quarta verso libeco, e alsi passando al campo di Buona Speranza per la inclinazione a scirocco; non ho tanto discorso ch'i'sappia ritrare se dalla calamita o dal sole o dalla regione procede." See Bertelli's notes [**122**].

[125] Bertelli [**122**].

[126] **Lettere edite ed inedite di Filipo Sassetti*, Florence, 1855, 206, 207.

[127] **Regionamenti sopra la varietà dei flussi et riflussi del mar Oceano occidentale*, Venice, 1574. Reference is on second page, unnumbered.

[128] Oviedo y Valdes, *Historia general y natural de las Indias*, first published, Madrid, 1535. It was preceded in 1525 (or 1526) by his *Summario de la natural hystoria de las Indias*. The best edition of the *Historia general* is that published in 1851 by the Royal Academy of History, Madrid (see lib. II, cap. 5, 11). In the latter chapter he refers to the needles being unreliable.

[129] Heathcote [**34**], p. 85, who points out that this may account for Fournier, *Hydrographie*, Paris, 1643, Bk. XI, 541, ascribing the discovery of declination to Oviedo. Most probably, Fournier consulted the French translation, which renders Oviedo's word for needles (aguajes) as "agitations des eaues."

[130] See [**120**].

[131] Pedro Nunes, *Tratado da sphera com a theorica do Sol e da Lua.*, Lisbon, 1537.

[132] For example, Herrera, *Historia general de los hechos de los Castellanos en las islas y tierra firme del Mar Oceano*, 4 vols., Madrid, 1601-15. Decad. I, Bk. I, ch. ix. English trans. by Stevens, London, 1740, I, p. 35. The quotation by Herrera is almost exactly as in Ulloa's translation.

[133] See Heathcote [**129**].

[134] Formaleoni [**27**], p. 53; see also Bertelli [**32**], 411-413.

[135] Harrisse, (a) *Jean et Sebastian Cabot: leur origine et leurs voyages*, Paris, 1882, Ch. I. Copies of all original documents are given in appendices. (b) *John Cabot, the discoverer of North America, and Sebastian Cabot his son*, London, 1896, pp. 29, 37. Reference may also be made to Biddle, *Memoir of Sebastian Cabot*, London, 1831, but with due weight assigned to Harrisse's criticism (*v. s.* p. 372).

[136] The only known copy of this map is now in the Bibliothèque Nationale, Paris. Full details, along with a reproduction of the map, are given by Harrisse [**135**], (*a*). Several writers refer to another copy having been found in Germany, but I have not been able to trace these to their source. See Harrisse, *v. s.* p. 153, note 1.

[137] See [**120**]. This book created much interest throughout western Europe. Later editions, Lyons, 1553, Venice, 1555, Rouen, 1573.

[138] The original letter of Contarini, dated 31 December 1522, is in the Biblio-

theca Marciana, Venice, and was published by Rawdon Brown, *Calendar of state papers and manuscripts relating to English affairs, existing in the archives and collections of Venice, and in other libraries of Northern Italy*, London, 1864-69, III, No. 558; republished by Harrisse [**135**], (*a*), 347-351.

[**139**] Bertelli [**52**], (*f*), Part IV, ch. xi, 63, gives a list of writers who dealt with this question. To this should be added, Besson, *La cosmolabe*, Paris, 1567, and Bourne, *Regiment of the sea*, London, 1577. That the idea occurred to Columbus was asserted by Humboldt [**21**], III, 38-40, but this cannot be sustained. The first to call the method in question was Cardan, *Practica arithmetica*, Milan, 1539 (*Opera*, III, 474). Gilbert [**97**] devotes Ch. IX, of Bk. IV to the question. He evidently thought there was more hope of finding the latitude from the dip (Bk. V., Ch. VIII).

[**140**] Livio Sanuto, *Geographia distinta*, Venice, 1588. Lib. I, cap. 2A.

[**141**] Gilbert [**97**], p. 4.

[**142**] Kircher, *Magnes, sive de magnetica arte*, Rome, 1641, p. 33.

[**143**] Fournier [**129**], 541, 545.

[**144**] Fontenelle, *Hist. Acad. Sci.*, 1712, Paris, 1714.

[**145**] Harrisse [**135**], (*b*), 290. Fontenelle evidently consulted the edition of Cabot's map published by Kochaff, *Variorum itinerarium delicia*, Harborn, 1594, p. 773. See Foscarini, *Della letteratura veneziana*, Venice, 1752, I, 439.

[**146**] For bibliographical and other details regarding Ruysch's map, see Harrisse [**135**], (*a*), 164-165. The map has been reproduced in Nordenskiöld's *Facsimile atlas*, Stockholm, 1889.

[**147**] Lelewel, *Géographie du moyen âge*, Brussels, 1852.

[**148**] See [**128**].

[**149**] See [**120**].

[**150**] Martin Cortés, *Breve compendio de la sphera y de la arte de navegar*, Seville, 1556; reproduced in Hellmann's *Neudrucke* [**40**].

[**151**] Nunes, see [**131**].

[**152**] Navarette, *Disertación sobre la historia de la náutica, y de las ciencias matemáticas*, Madrid, 1846, p. 179. In 1536, when this meeting was held, the pilots could only agree on three points at which the declination had been satisfactorily determined. "En Santo Domingo noruestaba dos cuartas el aguja, en la Habana dos y media, y tres en la Nueva España." But perhaps they were only confining attention to the West Indies.

I gladly take this opportunity to acknowledge with many thanks the help I have received from Reverend J. R. Macdonald, M.A., Edinburgh, and Miss A. Thompson, in the preparation of this article.

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COMPARISONS BETWEEN THE HORIZONTAL-INTENSITY VALUES AT THE OBSERVATORIES COPENHAGEN (RUDE SKOV) AND LOVÖ (STOCKHOLM)

By Sven Åslund

The standards in horizontal intensity (H) at Rude Skov and Lovö were compared in March, 1937, using the QHM-instruments 3, 5, and 7,[1] kindly placed at the disposal of the Lovö Observatory, Hydrographic Service, Stockholm, by the courtesy of the International Association of Terrestrial Magnetism and Electricity. The instruments were sent by mail between the two observatories and their constants were determined at Rude Skov. The observations with the QHM-instruments were made during several days at Lovö. The summary of the results is given below. It is to be remarked that the base-line values at the two observatories are provisional. The good agreement between the three instruments is remarkable.

Observations during March 2-13, 1937 at Lovö (Stockholm) gave the following values for the Observatory's base-line:

$$\left.\begin{array}{l} QHM_3 = 15285^{\gamma}.3 \pm 0^{\gamma}.2 \\ QHM_5 = 15285\ .2 \pm 0\ .3 \\ QHM_7 = 15284\ .9 \pm 0\ .4 \end{array}\right\} 15285^{\gamma}.1 \pm 0.^{\gamma}3$$

The preliminary base-line value at Lovö was 15292^{γ}, whence

$$\text{March 2-13, 1937, (Lovö—Rude Skov)} = +6^{\gamma}.9 \pm 0^{\gamma}.3$$

Several comparisons of the base-line values were made on previous occasions with the same types of instrument by Dr. V. Laursen and Dr. J. Olsen of Copenhagen and the writer at Lovö. The results then obtained were as follows:

February 3, 1935,	QHM_1,	(Lovö—Rude Skov)	$= +6^{\gamma}.8 \pm 0^{\gamma}.2$
February 20, 1935,	QHM_1,	(Lovö—Rude Skov)	$= +5\ .8 \pm 1\ .0$
April 9, 1935,	QHM_1,	(Lovö—Rude Skov)	$= +8\ .0 \pm 0\ .4$
July 23, 1935,	QHM_3, QHM_5, QHM_7	Lovö base-line	$= 15497\ .8 \pm 0\ .1$

The base-line at Lovö as determined by CIW-type magnetometer-inductor 108, of the Observatory, was 15504^{γ}, whence

		(Lovö—Rude Skov)	$= +6\ .2 \pm 0\ .1$
October 2, 1935,	QHM_3,	(Lovö—Rude Skov)	$= +5\ .9 \pm 0\ .5$

It will perhaps be of some interest to compare these results with those obtained with the CIW-type magnetometer-inductor 108, which instrument in ordinary cases is used as standard at Lovö. On three occasions in 1927, 1928, and 1935, Dr. G. S. Ljungdahl made comparisons at Copenhagen (Rude Skov) and found the following result as of 1927:

$$(\text{CIW } 108^2\text{—Rude Skov}) = +11^{\gamma}.0 \pm 0^{\gamma}.6$$

[1] D. la Cour, Le quartz-magnétomètre, Comm. Magnét. nr. 15, København, 1936.

corresponding to a logarithmic correction of the H-values $= -0.00030$. This correction has always been used *since then*.
Thus we have

$$\begin{aligned}
&\text{For 1927, (CIW 108—Rude Skov)} = 0^{\gamma}.0 \pm 0^{\gamma}.6\\
&\text{For 1928, (CIW 108—Rude Skov)} = +0\ .9 \pm 1\ .6\\
&\text{For 1935, (CIW 108—Rude Skov)} = +5\ .6 \pm 1\ .1
\end{aligned}$$

In 1929 Prof. Keränen made comparisons with Chasselon magnetometer 82 between Lovö and Rude Skov and found

$$(\text{Lovö—Rude Skov}) = -2^{\gamma} \pm 2^{\gamma}$$

It is interesting to note the change between the standards at Lovö and Rude Skov during the interval 1927 to 1937 as shown by the following final summary of all comparisons.

1927, (CIW 108—Rude Skov)	$= 0^{\gamma}.0 \pm 0^{\gamma}.6$	$= 0.00000H \pm 0.00004H$
1928, (CIW 108—Rude Skov)	$= +0\ .9 \pm 1\ .6$	$= +0.00006H \pm 0.00011H$
1929, (Chasselon 82—Rude Skov)	$= -2 \quad \pm 2$	$= +0.00013H \pm 0.00013H$
1935, (CIW 108—Rude Skov)	$= +5\ .6 \pm 1\ .1$	$= +0.00036H \pm 0.00007H$
1935, (CIW 108—QHM)	$= +6\ .5 \pm 0\ .5$	$= +0.00042H \pm 0.00003H$
1937, (CIW 108—QHM)	$= +6\ .9 \pm 0\ .3$	$= +0.00045H \pm 0.00002H$

The difference (Lovö—Rude Skov) is thus almost constantly increasing during the interval in question. A satisfactory explanation of this phenomenon has not hitherto been found.[3] The above shown changes seem to emphasize the need of frequent comparisons between the horizontal intensity standards at observatories.

[2]The constants have been determined at Washington in July 1927 and the correction was found to be 0^{γ} on I. M. S., the mean error being $\pm 1^{\gamma}.5$.

[3]*Note by Editor*—The author may not have taken account of probable change with time in the moment of inertia of the oscillation-magnet of CIW 108. This factor must be controlled, for magnetometric method, by inertia-determinations at intervals of one or two years—depending upon the amount of use of the magnetometer. The extensive experience of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington in intercomparing magnetic standards at a majority of the world's observatories, and for many and various types of field-instruments, indicates this to be a most important factor in apparent changing of standards with time shown by successive intercomparisons at the same observatory. [In this connection see *Researches*, Dept. Terr. Mag., **4**, 462-465 (1921), and J. A. Fleming, Trans. Edinburgh Meeting 1936, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. 10, 323-330 (Copenhagen, 1937)].

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ELECTROMAGNETIC METHOD FOR TESTING ROCK-SAMPLES

By A. G. McNish

Intensive study of the remanent magnetization of rocks should reveal information of profound importance to investigators in terrestrial magnetism and geology. If magnetic precipitates are permitted to settle from a solution the particles align themselves so that the sediment is magnetized in the direction of the prevailing magnetic field. Similarly, a magnetic substance when cooling, if its original temperature is above the Curie point for that substance, becomes magnetized in the direction of the prevailing field. For these reasons both sedimentary and igneous rocks may be expected to assume a magnetic condition corresponding to the Earth's magnetic field prevailing at the time and place of their formation. It is quite likely that such magnetization is retained. Thus both sedimentary and igneous rocks may supply a comprehensive record of the Earth's magnetic state in past geologic ages—a record of such length that the human race may never hope to duplicate it by direct instrumental observation.

The inferences which may be drawn from such measurements, if the hopes and expectations are borne out, fall into two classes. The first, of greatest interest to magneticians, concerns the history of the Earth's magnetic field. From sedimentary rocks which may be accurately dated, such as the varved deposits found in old glacial lakes, a year-by-year record of magnetic declination, at least, should be obtainable. Such a series may be extended over several thousands of years, using deposits from various lakes where cross-dating has been possible and working out a sort of station-difference from simultaneously deposited layers. Measurements of magnetic inclination would, of course, be subject to greater uncertainty. The second class, of greatest interest to geologists, concerns the association of magnetic properties of various rocks. This may permit a rapid dating of rock-samples by associating their magnetization with rocks of known age. Provided changes in the Earth's magnetic field have been sufficiently marked from one geological epoch to another, considerable information may be obtained in this way.

The scientific significance of systematic studies of this "fossil" magnetization is intriguing. From them one may hope to decide whether the secular variation of the Earth's magnetism through the ages exhibited periodic characteristics—as is suggested by much of the short-time data—or whether it varied quite randomly. Perhaps from such studies the possibility of a complete reversal of the Earth's magnetic field with respect to the surface-rocks may be definitely settled. If magnetic cross-dating becomes an actuality, connections between the American and European glacial deposits may be established.

In offering these suggestions it is emphasized that they represent only hopes— not realizations. The possibilities presented, if the underlying assumptions are found to be fulfilled, are so great that attempts

at their solution at the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, have been authorized by Dr. J. A. Fleming, Director, in hopes that some of the riddles of terrestrial magnetism may be clarified.

Experiments have already been conducted on methods of measurement. Since exposure of the rock-samples to strong magnetic fields may alter their magnetization, common methods of magnetic testing may not be used. Instead, the specimens have been rotated inside a coil connected to a tuned amplifier designed and built by E. A. Johnson[1] of the Department of Terrestrial Magnetism. The output of the amplifier was connected to a cathode-ray oscillograph by means of which the induced electromotive force was measured.

Rock-samples obtained from ocean-bottoms by the apparatus designed by Dr. C. S. Piggot of the Geophysical Laboratory, Carnegie Institution of Washington, have been examined with this device. Although the samples exhibited appreciable magnetization no satisfactory quantitative results have yet been obtained. Principal difficulties arise through vibration of the testing coil in the Earth's field when the specimen is rotated. Ultimately it is hoped to shield the apparatus and the rotating specimen from the Earth's field by the counter magnetic field of a large Helmholtz coil and to eliminate short-period fluctuations by shields of heavy brass.

By rotating the specimen about three orthogonal axes the total magnetization may be measured. Sense of the magnetization may be determined by phasing the output of the amplifier with the rotating specimen through a commutator or by mounting a small test-magnet with the specimen and adjusting it for minimum effect. The small test-magnet will also serve for calibration.

It is hoped that the publication of this short note may elicit comments and suggestions to further prosecution of the work. Already the project has been encouraged by the advice and suggestions of many investigators who are interested in the furtherance of geological and terrestrial-magnetic science. In particular, recognition must be given the writer's colleague, E. A. Johnson, whose technique in the measurement of small voltages is the basis of the method which has been outlined, and to V. Vacquier of the Gulf Research and Development Company, who suggested the application of this technique to the problem.

[1]Physics, 7, 130-132 (1936).

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MEASUREMENT OF AIR-POTENTIALS BY THE LEAK-FREE AND NULL METHOD

By K. L. Sherman

The purpose of this paper is to report further on a leak-free and null method of making electrostatic measurements. The method and some results obtained when applied to observations of air-potentials have previously been given.[1] Whereas the leak-free feature of the method was stressed in that report, it is desired now to emphasize some of its other advantages and to describe small, convenient units designed to replace the more cumbersome apparatus assembled in the laboratory for the preliminary trials.

Reports from persons who have used the method have consistently indicated that it is worth while adopting because of the ease of observation and reduction of the data even though the leak-free feature is not used. Although the circuit is somewhat more complex than the conventional one and so requires slightly more time to prepare for an observation, the total time of a set of observations is less with this method because it saves the time required to calibrate the electrometer and to convert the electrometer-readings to volts.

Adoption of this arrangement for work in the laboratory and at several observatories for control and standardization of potential-gradient observations led to the design and construction of units to facilitate connecting the necessary apparatus and making the observations.

Figure 1 is a schematic diagram of the circuit used showing a bifilar

[1] O. H. Gish and K. L. Sherman, Terr. Mag., 34, 231-237 (1929).

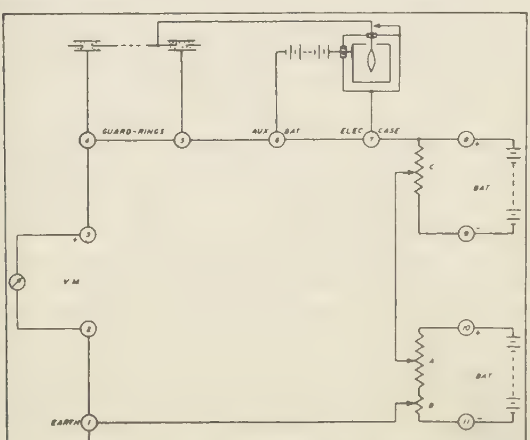

FIG. 1—LEAK-FREE AND NULL METHOD FOR MEASURING AIR-POTENTIALS

electrometer connected to an insulated collecting-system as for measuring the potential of the air. It also indicates the layout as incorporated in the new potential-regulator and hook-up box. The completed assembly may be seen in the photograph of Figure 2. Eleven binding-posts indicated by the small circles (1 to 11) are mounted around the edge of

a panel of bakelite which forms the cover of a wooden protecting box. Beside each post the point to which it is to be connected is engraved in the bakelite, making it unnecessary to follow a wiring diagram when setting up. The resistors are small, inexpensive, wire-wound, Yaxley potentiometers. *A* and *C* are 50,000-ohm type-E units while *B* is a 3000-ohm type-*M* unit. *A* and *B* with the batteries connected to them cover the usual range of potentials. *B* is provided to obtain more accurate settings. Resistor *C* and the binding-posts connected to it need not be used at all; they were provided to easily increase the range of the apparatus and to cut down the current-drain on the batteries. Thus if it is desired to measure larger positive potentials than can be obtained from the batteries connected to *A* and *B*, the reserve batteries are connected to posts 8 and 9 with polarity as indicated by the labels. Should it be desired to measure negative potentials as well as positive, these batteries may be connected in with the connections reversed from that indicated by the labels and of course using a zero-center voltmeter or also reversing the leads to the voltmeter as needed.

With resistors of this size and using a 30,000-ohm voltmeter the drain on the batteries is small. For example, with standard-size radio *B*-batteries, say Burgess No. 2308, to measure average air-potentials of 100 volts, more than 1000 hours' use may be expected when used in intermittent service four hours per day.

To indicate specifically what is required for preparation and operation the following description of the detailed routine followed when making potential-gradient standardization-observations is given:

Preparation The stretched-wire system is erected as usual and the electrometer, voltmeter, regulator-unit, and batteries are located in a convenient place for manipulation. Since the outer case of the electrometer is to be at the potential of the fiber-system, sufficient insulation must be provided between this case and earth so as not to put an excessive drain on the batteries.

The insulated fiber-system of the electrometer is now connected to the outer case so as to prevent the fibers from being deflected so far as to be injured by any of the subsequent operations. A contacting plunger, with which some of these electrometers are fitted, is convenient for this purpose. Now the collecting-system is connected to the insulated system of the electrometer. It is desirable to apply the potential from an auxiliary battery between the inner and outer cases of the electrometer to deflect the fibers to the sensitive portion of the scale. This also enables the observer to determine at a glance whether the collecting-system is positive or negative with respect to the case of the electrometer. For this discussion it will be assumed that the positive terminal is connected to the inner case of the electrometer, then the negative terminal connects to the binding-post on the hook-up box marked "Aux. Bat." In fact the rest of the circuit-connections are completed by connecting up all eleven terminals on the box to points as indicated by the labels beside each as follows: "Earth" to the ground stake; "V.M., + and −" to the terminals so marked on the voltmeter; "Guard Rings" to specially provided rings or to the metal shell of the sulphur-insulators frequently used; "Aux. Bat." as already indicated above; "Elec. Case" to the outer case of the electrometer; "Bat., + and −" (10 and 11) to a bank of batteries which will furnish positive potentials to cover the anticipated range; "Bat., + and −" (8 and 9) to another bank of batteries as for 10 and 11, or not used, or used with the connections reversed as needed.

Operation—Since the fiber-system is still in contact with the outer case, the fibers are deflected to the null position. This may be adjusted by moving the microscope so as to bring the fibers to an even division or other easily recognized position on the scale.

Now with the fiber-system disconnected from the outer case, action of the collector will cause the fibers to change deflection unless by chance their potential is already that of the air. As they are deflected they are brought back to the null position by turning the dials of the regulator. If connected as indicated the deflection decreases as the fiber-system becomes more positive and the regulator-dials must be turned clockwise to return them to their null position.

After watching the fibers and adjusting for their movement until it is seen that action of the collector has brought the fiber-system to the potential of the air, the practice regularly followed is to return the fiber to the null position and so to read the potential of the air directly from the voltmeter once each minute. Occasionally, say once during each 20-minute set, the fiber-system is connected to the outer case to observe the null position. Ordinarily this is found to be unchanged but because it may be done quickly and without interruption to the series—since the collector-system is not discharged by so doing—it is worth while to take this precaution. By observing the motion of the fibers after they are again free to follow the potential of the air, one may also check on another remote possibility, namely, that the potential of the outer case instead of being the same as that of the air is less than that by an amount equal to twice the difference of potential between the inner and outer cases, since the fibers would have the same deflection for both conditions.

Although this device is convenient for the measurement of other

elements, the circuit and the procedure outlined above should be examined for needed modification, before adopting them for other applications. For example, should it be desired to determine the electromotive force of a battery, the above routine would need to be altered so as not to short circuit the source by connecting the fiber-system to the outer case with the battery-circuit closed.

The specific applications given above are included to indicate the simplicity and adaptability of the method. Use with other apparatus for measurement of other elements will be obvious upon examination of the circuit.

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ELECTRICAL POTENTIAL-GRADIENT AND CONDUCTIVITY OF AIR NEAR RAPID CITY, SOUTH DAKOTA

By K. L. Sherman and O. H. Gish

Abstract—Air-potentials and air-conductivity were recorded at a location about 15 miles south and west of Rapid City, South Dakota, during periods of preparations for the flight of *Explorer II* in 1935. The semi-portable apparatus was installed in a hut on the rim of the natural bowl in which the balloon was to be inflated. The recorded values of air-potentials were compared with several series of eye-observations made on a plain about one mile away, in order to reduce the registrations to volts per meter. Positive and negative conductivity were recorded on alternate days with the single apparatus. The average values for selected complete days of record during June to July and during September to November, respectively, were: Potential-gradient, 80 and 69 volts per meter; positive conductivity, 3.09 and 3.44×10^{-4} electrostatic unit; negative conductivity, 2.43 and 3.14×10^{-4} electrostatic unit. Harmonic analyses show that a 24-hour component exists in gradient, in agreement with Mauchly's findings. A comparison with ocean-values indicates that but a small part of the diurnal variation is of local character. The diurnal variation in air-conductivity is approximately the inverse of that in gradient but of less amplitude. The product of the gradient and total conductivity—the electrical conduction-current—therefore varies in a manner similar to the gradient.

Simultaneous registrations of the electrical potential-gradient and of the conductivity of air were obtained near Rapid City, South Dakota, during May to July and September to November, 1935, through the co-operation of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington with the National Geographic Society and the United States Army Air Corps. These series were obtained while waiting for a suitable day for the flight of the Stratosphere Balloon *Explorer II* and also during the flight (November 11, 1935). It was thought that these data should be of value when interpreting the air-conductivity registrations obtained during the flight with apparatus which was mounted on the gondola of the balloon. Furthermore, it seemed that such data should constitute a worth-while addition to the available information about the approximate magnitude of the atmospheric-electric elements at the Earth's surface and about the manner in which they vary during the day. This was deemed particularly the case because the mid-continental position from which the flight was to start is one which is usually relatively free from the sources of atmospheric pollution, such as industrial centers, and other factors which tend to give the electric phenomena more complicated aspects. This desideratum is especially important at a place where limitations of equipment and personnel prohibit the elaborate program of measurements required for an adequate study of the effects of pollution and of the local characteristics in the electric phenomena which arise from such effects.

This report is essentially a description of the results obtained from the registrations made at the Earth's surface. Their relation to the air-conductivity measurements obtained on the flight is discussed in a separate report.[1]

Location—The camp, which was established to care for the personnel connected with the flight, was located in the "Stratobowl" on the north-

[1] O. H. Gish and K. L. Sherman, Tech. Papers, Nation. Geog. Soc., Stratosphere Ser. No. 2, 94-116 (1936).

eastern border of the Black Hills and about fifteen miles south and west of Rapid City, South Dakota. A suitable location for setting up the recorders in a simple shelter was found about one mile from the camp on the higher surrounding ground in latitude 43° 58′ north and longitude 103° 21′ west, at altitude 1200 meters above sea-level. The immediate vicinity was grazing land, fairly open and rolling, although to the north and west the area is generally wooded. A fence was erected around the shelter to prevent cattle from damaging the apparatus or from approaching near enough to appreciably affect the registrations. The view toward the northwest is shown in Figure 1. Standardization observations for

the potential-gradient were made on an open meadow about one mile distant; the character of the terrain there is shown in Figure 2.

Equipment for registering air-potential—A small building about five feet square and six feet high was erected for the "observatory." The rod to which the ionium-coated collector-disc of the potential-gradient apparatus was attached projected about three feet from the side of the building at a height of five feet. The rod was supported by two circular amber-insulators mounted in a box in such a way that drying material could be used to remove the moisture from the air surrounding the

Registrations were obtained by a Günther and Tegetmeyer recording bifilar-electrometer which had been modified so that the connection from the electrometer-terminal to the collecting-system was made directly, thus eliminating one insulator from the original design. A new contact-device, wholly inside the cap of the electrometer, earthed the entire insulated system once an hour, thus providing reference-points for time and base-line. The electrometer-sensitivity was such that 20 volts deflected the image of each fiber about one mm, so that an average deflection on the registrations was about four mm. By maintaining the inner case at a potential of −90 volts the more sensitive and linear range of the electrometer was in use for normal registrations and a means provided for determining the sign of the recorded air-potential.

Equipment for registering air-conductivity—An old Gerdien conductivity-apparatus of portable type was modified for use on this Expedition. The hand-operated fan was replaced by a six-volt motor-driven fan such as is used in automobiles. A freshly charged six-volt storage-battery of capacity about 80 ampere-hours served as an adequate source of power for operating the motor, the recorder lamps, and the charging relay for 24 hours. A Günther and Tegetmeyer recording bifilar-electrometer, which was fitted to the Gerdien condenser, made a record of the rate of discharge of the insulated collecting-system. A new clock-cam, with four off-sets instead of one, controlled the contactor in the electrometer-cap so that the collecting-system was recharged every fifteen minutes to a potential of 180 volts which was supplied by four 45-volt "B"-batteries. The rod supporting the central cylinder of the air-flow tube was mounted directly to the terminal of the fiber-system in the main insulator of the electrometer, which was then the only insulator of this system.

Factor for converting registered air-potential to gradient—The standardization-observations required for reducing the recorded air-potentials to volts per meter were made by the stretched-wire method of Simpson and Wright, in which two ionium-coated collectors were held one meter above the Earth's surface at the center of an insulated wire which was stretched horizontally between two posts about 24 meters apart. The wire was connected to an eye-reading bifilar-electrometer which served as the indicating instrument in a null-method.[2] This method, which avoids loss of charge across the insulators, is convenient since the reading of a voltmeter gives the gradient in volts per meter directly when the collector is kept at a height of one meter. The potential-dividers and variable resistors required in this method are the inexpensive type made for radio equipment. These are mounted in a "hook-up" box and are provided with labelled binding-posts which facilitate making the necessary connections when setting up in the field. This unit, which was built in the instrument-shop of the Department, was found to be very convenient and entirely satisfactory for the purpose. Standardization-observations were made on four days in June and July. These comprised 45 sets, each consisting of 20 readings taken at intervals of one minute. The mean value of the reduction-factor from these 45 sets was 1.00. The mean value obtained from twenty 20-minute sets on two days in October was 0.99. Accordingly the factor of 1.00 was used throughout in the reductions. Despite the considerable distance between the

[2]O. H. Gish and K. L. Sherman, Terr. Mag., **34**, 231-237 (1929).

recording station and the standardizing site the "scatter" in the ratios is about the same as in values obtained at the Carnegie Institution of Washington observatories where the standardizing station is near the observatory. The standard deviation of the means for the six individual days from their common mean was 0.08.

Operation—The observatory was visited in the morning and evening of each day to make the necessary tests and control-measurements. Tests of the insulation of the potential-gradient and conductivity collecting-systems were made each time. When testing the insulation on the potential-gradient system the rod carrying the collector was removed from the mounting, then the system was charged to a convenient potential and the rate of discharge was recorded. By thus removing the rod rather than the collector alone, changes caused by induction from the Earth's field were negligible and a more satisfactory test resulted. Insulation-tests on the conductivity-apparatus were made by stopping the motor and closing the ends of the air-flow tube and then recording the rate at which the system discharged. After these tests were completed examination was made for spider-webs or other possible sources of defective insulation, even though the discharge-rate had appeared to be satisfactory. The gaps between the potential-gradient collector-rod and the earthed portions of the apparatus were always swept at these times to clear away webs or other foreign materials even though none could be seen. Each instrument was calibrated over its normal range of registration once each day. Fresh drying material was installed as often as needed for removing the moisture from the air in contact with the insulators supporting the collecting-systems. By setting the clocks to correct time each day, if necessary, the greatest departure from correct 105° west meridian time was usually less than two minutes, which could be ignored when evaluating records. As a rule the conductivity of one

Table 1—*Mean hourly values in volts per meter of potential-gradient near Rapid City, South Dakota, June and July, 1935*

Date	Greenwich mean time in hours											
	0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12
June 2	80	71	69	67	65	69	80	90	88	88	84	71
4	92	82	69	50	48	48	59	67	69	65	65	69
5	105	101	67	59	59	63	67	57	59	61	67	84
7	76	63	59	57	65	67	67	65	59	71	65	59
8	92	74	59	52	55	38	38	36	38	46	38	36
9	67	63	59	59	59	69	71	67	76	82	99	97
12	69	67	63	59	61	61	55	61	57	55	52	52
14	92	88	69	61	61	55	57	55	55	55	52	44
22	90	90	78	90	76	61	61	55	46	46	52	59
25	90	94	88	69	88	97	76	76	76	74	82	86
26	122	105	78	55	48	42	52	50	55	61	76	84
28	88	69	63	57	55	55	59	48	59	50	48	55
29	76	67	63	50	46	50	52	65	67	63	65	69
30	63	65	57	57	48	36	46	59	69	63	63	69
July 5	67	63	55	65	57	46	34	32	42	44	48	42
11	88	84	63	63	59	57	59	67	63	82	82	84
Means	85	78	66	61	59	57	58	59	61	63	65	66

Greenwich mean time in hours

12–13	13–14	14–15	15–16	16–17	17–18	18–19	19–20	20–21	21–22	22–23	23–24	0–24
48	55	69	63	84	88	94	92	90	101	90	90	79
74	84	97	105	107	105	105	105	103	101	99	92	82
88	99	103	94	90	92	101	103	101	74	61	59	80
65	101	99	101	120	136	141	141	122	120	107	90	88
42	57	67	67	65	63	46	46	50	78	84	74	56
84	103	101	105	103	103	105	94	88	80	67	67	82
63	69	105	116	105	116	111	132	126	128	139	126	85
57	78	103	105	122	124	103	109	105	105	105	101	82
67	88	105	116	120	111	124	111	116	116	109	107	87
113	116	111	113	111	118	132	122	113	111	126	122	100
88	107	101	120	118	103	99	80	78	90	99	94	84
76	82	90	86	101	99	101	105	111	105	92	86	77
69	71	67	69	69	76	82	88	86	84	88	94	70
69	61	63	74	78	84	84	84	88	101	105	103	70
46	59	84	86	94	84	94	105	105	101	105	101	69
84	84	88	86	111	105	105	97	97	92	99	90	83
71	82	91	94	100	100	102	101	99	99	98	94	80

sign was recorded one day and that of the other sign on the next day. A multiple-contact switch was so wired that the sign of the charging potential and that of the potential between the inner and outer cases of the electrometer could be changed in one operation. This was done at 17^h, 105° west meridian time, which corresponded to Greenwich midnight. Thus in working up the data days were readily selected and tabulations were made on the basis of Greenwich time.

Treatment of data.—The mean hourly values of potential-gradient are given in Tables 1 and 2 for all days on which the registration was complete and without negative or abnormally high positive potentials. Only two days, one in each series, namely, July 9 and November 10, were rejected because of the latter restriction alone. Twenty-three days in the series during spring were excluded because of the occurrence of negative potentials; one day was incomplete. In the series during fall twelve days were rejected because negative values were registered and two days were incomplete.

For conductivity the same days as in the case of potential-gradient were selected, except that days were omitted if the record was incomplete or if the insulation—as indicated by the routine tests—was defective. Two days in the spring were rejected for the latter cause and three for the former. Five days in the fall were rejected because of excessive discharge-rate during insulation-test and three because the record was incomplete.

The accuracy of the conductivity-measurements is probably less than that of the potential-gradient measurements for the following reasons: (1) The discharge during the insulation-test of the conductivity-apparatus which was made with the air-flow stopped depends not only on the conductance of the insulator but also upon the conductance of the quiet air within the Gerdien condenser due to radioactive matter which is deposited from the air onto the walls of the condenser. Although it is desirable to correct the registrations for this residual conduction, yet that correction is not correctly determinable from the discharge-rate

TABLE 2—*Mean hourly values in volts per meter of potential-gradient near Rapid City, South Dakota, September, October and November, 1935*

Date	Greenwich mean time in hours											
	0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12
Sep. 29	67	50	42	40	46	42	42	42	42	46	50	59
30	42	42	46	50	52	61	59	59	63	59	63	63
Oct. 1	48	42	42	42	32	29	27	27	25	25	27	32
5	42	40	38	42	42	40	36	38	40	42	38	36
8	38	36	38	40	40	42	42	40	42	61	61	61
10	80	67	48	67	57	48	48	50	50	52	36	36
11	46	40	38	36	36	32	29	38	40	42	40	40
12	67	67	67	59	63	63	63	63	84	92	69	63
13	46	42	34	46	63	63	63	65	67	69	69	80
14	71	65	59	48	55	59	61	59	46	42	42	55
17	57	59	50	48	55	52	50	57	67	55	55	59
19	42	42	42	42	38	42	42	42	40	38	42	42
23	46	42	48	61	67	63	52	42	63	84	88	105
24	59	67	57	48	50	50	48	46	48	48	48	50
25	63	59	50	57	61	55	48	48	44	42	42	42
26	55	48	50	55	48	48	46	42	42	36	36	40
27	46	46	48	52	52	52	52	52	50	46	42	50
29	63	55	55	59	63	63	63	63	55	50	42	46
Nov. 2	90	71	63	63	57	42	57	55	67	74	67	63
4	46	55	42	40	42	44	42	34	40	55	36	40
5	86	88	105	105	63	63	67	69	69	63	57	55
6	74	82	69	69	76	71	67	67	59	55	63	46
7	44	42	44	59	63	61	55	65	69	63	67	71
11	67	76	74	76	71	63	61	61	59	55	69	63
Means	58	55	52	54	54	52	51	51	53	54	52	54

Date	Greenwich mean time in hours												
	12–13	13–14	14–15	15–16	16–17	17–18	18–19	19–20	20–21	21–22	22–23	23–24	0–24
Sep. 29	63	67	76	84	99	101	103	101	92	84	84	80	67
30	69	74	90	105	105	109	116	111	118	97	84	76	76
Oct. 1	32	42	59	67	74	74	71	71	74	69	67	61	48
5	40	40	38	99	97	105	105	101	88	80	63	59	58
8	61	63	84	90	105	105	105	105	105	90	80	69	67
10	36	40	46	69	67	67	105	122	105	101	84	63	64
11	44	46	74	103	120	124	122	126	97	105	105	84	67
12	67	82	84	84	86	88	101	94	90	84	84	63	76
13	71	105	107	120	107	103	103	136	126	111	99	90	83
14	78	78	76	84	105	84	99	101	101	90	69	63	70
17	67	80	111	113	118	122	120	132	120	99	88	63	79
19	44	48	69	84	84	99	105	84	57	84	84	76	59
23	92	63	92	94	111	113	116	126	105	94	88	55	80
24	52	50	63	74	90	92	109	105	99	82	78	69	66
25	50	48	65	84	84	94	105	126	116	105	78	63	68
26	40	42	48	90	105	118	120	120	122	105	90	61	67
27	63	71	84	90	105	105	113	109	105	90	65	61	69
29	42	46	48	80	109	116	109	103	88	84	80	46	68
Nov. 2	63	78	82	90	109	139	107	84	109	25	32	63	73
4	42	44	52	65	90	99	105	105	90	71	84	97	61
5	63	69	42	63	82	90	103	90	84	86	76	69	75
6	59	65	63	80	84	84	67	67	63	50	42	42	65
7	82	84	92	84	90	90	82	124	105	90	63	63	73
11	59	61	84	94	101	101	111	116	103	86	71	63	77
Means	57	62	72	87	97	101	104	107	98	86	77	67	69

observed when the air-flow is stopped. Furthermore, the required correction may vary during the day in a manner which could not be determined with the limited equipment. (2) Defective insulation affects the recorded conductivity more directly than is the case for the air-potential because for the latter the effect of insulation-conductance depends on the ratio of that conductance to the conductance-factor of the collector. Thus if the activity of the collector is large the demand upon the insulation is relatively small. The activity of the collector used in this work was such that an insulation-resistance of 1000 esu would give an error of only 0.1 per cent in the recorded potential. However, if the prime insulation of the conductivity-apparatus is of that quality the error in the recorded values would be about five per cent. (3) The average conductivity was found to be larger than had been expected so that—even with the provision for recharging the system at 15-minute intervals—on some days potential at the end of an interval was so near zero that a slight error in scaling the trace would entail large absolute errors. While it is not certain that the conductivity-data were appreciably affected by errors from either of the first two sources, there is evidence for concluding that errors from the last-mentioned source may be great enough and of such character as to depress the maximum in the diurnal variation and, to a lesser extent, reduce the average value of this element on some days.

In view of these considerations the conductivity-data are reported in less detail than are those for potential-gradient, the hourly means for groups of days (spring and autumn) being given instead of those for individual days. An average correction of six per cent, based on the rate of discharge observed when the air-flow was stopped, has been applied to the values given. The average magnitude of the conductivity and the general character of the diurnal variation are doubtless approximately as indicated by these data even though some of the details may be unreliable.

The mean values of both positive and negative conductivity given in Table 3 were obtained from records for the following days: In the series during spring, for three days of positive conductivity (June 2, 4, and 8), and for eight days of negative conductivity (June 5, 7, 9, 12, 22, 25, 26, and July 11); in the series during fall, for nine days of positive conductivity (October 5, 13, 19, 23, 25, 27, November 5, 6, and 11) and for seven days of negative conductivity (October 8, 12, 14, 24, 26, November 7 and 8).

The values for air-earth current given in Table 3 were obtained by multiplying a mean value of potential-gradient by the sum of the mean value of positive and that of negative conductivity for a corresponding hour of the day. Although aware that this method of calculating air-earth current may be criticized on several scores, the authors deem it the best compromise that could be made under the circumstances. It was not possible to calculate values from individual hourly means of gradient and total conductivity because the two polar conductivities were not registered simultaneously but on alternate days. Furthermore, it seemed advisable to use all data which satisfied the criteria for selection in order to suppress those features which occur at random. On this account the data for potential-gradient are more extensive than those for conductivity. The sum of the polar conductivities was used, instead of the

Table 3—*Average hourly values of air-conductivity and air-earth current near Rapid City, South Dakota, 1935*

Period and element	Greenwich mean time in hours											
	0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12
June to July												
λ_+ (3 days)	2.96	3.01	3.07	3.33	3.27	3.62	3.70	3.43	3.29	3.26	3.38	3.45
λ_- (8 days)	2.65	2.68	2.67	2.61	2.80	2.83	2.67	2.72	2.73	2.74	2.72	2.59
$(\lambda_+ + \lambda_-)$ in 10^{-4} esu	5.61	5.69	5.74	5.94	6.07	6.45	6.37	6.15	6.02	6.00	6.10	6.04
Current in 10^{-7} esu	15.9	14.8	12.6	12.1	11.9	12.3	12.3	12.1	12.2	12.6	13.2	13.3
Sept. to Nov.												
λ_+ (9 days)	3.06	3.07	3.41	3.44	3.41	3.70	3.71	3.78	4.07	4.17	4.15	4.17
λ_- (7 days)	2.78	2.77	2.96	3.37	3.22	3.36	3.54	3.54	3.69	3.80	3.62	3.54
$(\lambda_+ + \lambda_-)$ in 10^{-4} esu	5.84	5.84	6.37	6.81	6.63	7.06	7.25	7.32	7.76	7.97	7.77	7.71
Current in 10^{-7} esu	11.3	10.7	11.0	12.3	11.9	12.2	12.3	12.4	14.7	14.4	13.5	13.9

Period and element	Greenwich mean time in hours												
	12–13	13–14	14–15	15–16	16–17	17–18	18–19	19–20	20–21	21–22	22–23	23–24	0–24
June to July													
λ_+ (3 days)	3.56	3.85	3.37	3.42	2.88	2.44	2.37	2.38	2.38	2.47	2.54	2.72	3.09
λ_- (8 days)	2.67	2.80	2.47	2.22	2.02	1.88	1.94	1.98	1.98	2.02	1.98	1.97	2.43
$(\lambda_+ + \lambda_-)$ in 10^{-4} esu	6.23	6.65	5.84	5.64	4.90	4.32	4.31	4.36	4.36	4.49	4.52	4.69	5.52
Current in 10^{-7} esu	14.7	18.2	17.7	17.7	16.3	14.4	14.7	14.7	14.4	14.8	14.8	14.7	14.3
Sept. to Nov.													
λ_+ (9 days)	4.12	3.99	3.79	3.36	3.24	2.83	2.82	2.72	2.67	2.69	3.00	3.16	3.44
λ_- (7 days)	3.50	3.28	3.43	3.20	2.95	2.76	2.58	2.44	2.41	2.75	2.73	3.02	3.14
$(\lambda_+ + \lambda_-)$ in 10^{-4} esu	7.62	7.27	7.22	6.56	6.19	5.59	5.40	5.16	5.08	5.44	5.73	6.18	6.58
Current in 10^{-7} esu	14.5	15.0	17.3	19.0	20.0	18.8	18.7	18.4	16.6	15.6	14.7	13.8	14.7

positive conductivity alone, because it is thought that since the measurements are made at a height of 1.5 to 2 meters from the surface the values thus obtained should be the better approximation.

Results—The average potential-gradient is greater and the average conductivity is less for the summer than for the autumn, which is contrary to the annual trend usually observed at other land-stations. That this is not the result of abnormal values occurring on a few days is indicated by the fact that the "probable error" of the respective means is only one-tenth to one-seventh of the difference of the mean values for the two seasons. The mean air-earth current, however, is essentially the same for the two seasons, hence the reciprocal relation between potential-gradient and total conductivity applies to this change. A

comparison of the quantitative change in several of the elements is of interest. From summer to autumn positive conductivity increased 11 per cent, whereas the negative conductivity increased 29 per cent; air-earth current increased only 2.7 per cent; the ratio of positive to negative conductivity decreased 13 per cent and the potential-gradient decreased 14 per cent. This evidence is taken to indicate that the "electrode-effect" was considerably more evident during the summer than during the autumn and that the circumstances which gave rise to the change between the two series of observations were largely confined to a stratum of air which extended to altitudes greater than those where the electrode-effect is appreciable but probably did not extend much beyond an altitude of one km. Had it extended farther the air-earth current should have changed more. The reason for concluding that circumstances responsible for the change extend higher than the region of the electrode-effect is that the ratio of the observed gradient to that at levels where the elec-

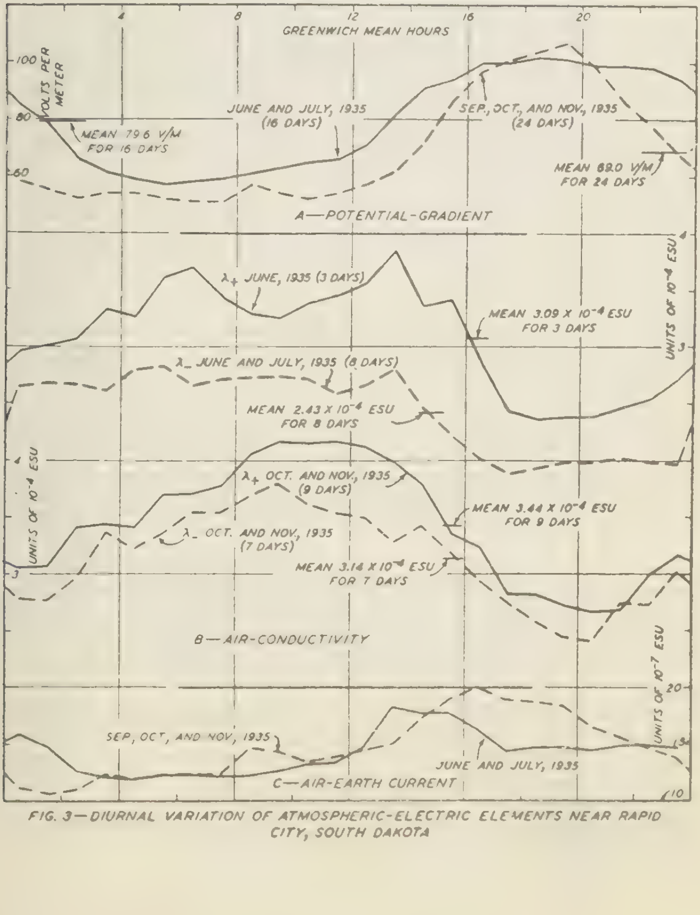


FIG. 3—DIURNAL VARIATION OF ATMOSPHERIC-ELECTRIC ELEMENTS NEAR RAPID CITY, SOUTH DAKOTA

trode-effect is inappreciable, as calculated according to the theory of Scholz,[3] would need to be about 1.10, on the average, in order to be consistent with the average ratio of positive to negative conductivity observed at this place.

The character of the diurnal variation in both potential-gradient and conductivity is shown in Figure 3. The graphs for the gradient are definitely more regular than those for conductivity. This is not due entirely to the fact that the values for potential-gradient are means from a greater number of data than are those for conductivity, since that contrast was also noticeable when comparing individual records of the two elements.

Comparison with other results—It is of interest to compare these results with others obtained in America. Wait[4] briefly discussed published results of potential-gradient over this area in a report on a short series of potential-gradient registrations made at Penalosa, Kansas. Figure 4 is a diagram taken from his paper presenting his results in com-

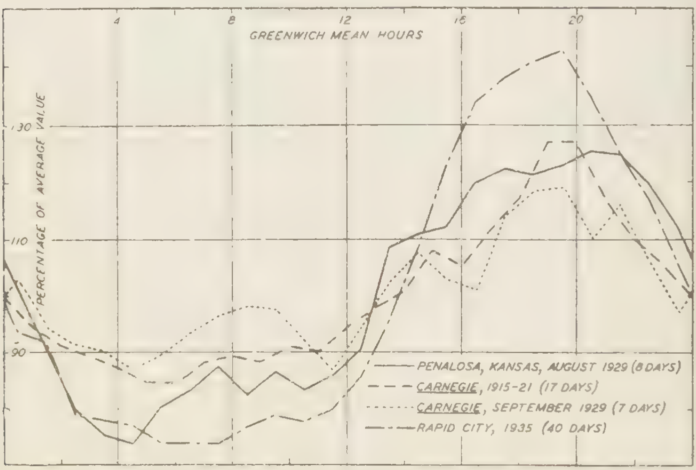


FIG. 4—COMPARISON OF DIURNAL VARIATION OF ATMOSPHERIC POTENTIAL-GRADIENT RECORDED AT RAPID CITY, SOUTH DAKOTA, PENALOSA, KANSAS, AND ABOARD THE *CARNEGIE*

parison with those obtained on the *Carnegie*. To this diagram has been added the curve from the 16-day series obtained at Rapid City in June and July, 1935. The comparison is carried further in Table 4 where the results of a harmonic analysis of the mean curves for both series in the spring and fall are given along with data from Wait's table. The close agreement of the phase-angle of the 24-hour wave adds another link to the chain of evidence for the existence of such a wave occurring according to universal time. These data indicate that it is the predominating feature over land-areas which are situated so as to be relatively free from the effects of local pollution of the atmosphere

[3]Wien. SitzBer. Ak. Wiss. II*a*, **140**, 49-66 (1931); some results, without the argument, of a similiar consideration are given by E. Schweidler in Einführung in die Geophysik, II, 345-346 (1929).

[4]Terr. Mag., 35, 137-144 (1930).

TABLE 4—*Summary of harmonic analyses of observed diurnal-variations of atmospheric potential-gradient*

Locality	Period	Computed phase-angles		Computed amplitudes		Ratio c_2/c_1
		ϕ_1	ϕ_2	c_1	c_2	
		°	°	*per cent*	*per cent*	
Pacific Ocean	Sep., 1929 (7 days)	165	224	12	5	0.39
Kansas	Aug., 1929 (8 days)	169	196	24	5	0.21
Atlantic, Pacific, Indian Oceans	Aug., Sep., and Oct., 1915, 1916, 1920, 1921 (17 days)	167	217	17	5	0.29
South Dakota	June and July, 1935 (16 days)	164	169	30	2	0.07
South Dakota	Sep., Oct., and Nov., 1935 (24 days)	170	250	36	16	0.44

Johnston and Wait[5] summarized the results of observations of air-conductivity from stations occupied by the Carnegie Institution of Washington and also repeated values published by Benndorf and Hess. The mean value of total conductivity from the present series of about 6×10^{-4} esu lies between that found at Tucson, Arizona, and that at Huancayo, Peru. (Yearly mean values for Tucson for the year 1931 have been given[6] as 4.3×10^{-4} esu for total conductivity and 48 volts per meter for gradient.) It should be noted that the altitude of the present station is about 1200 meters, also intermediate between the altitudes of these two stations.

Few published data are available for a satisfactory comparison of the diurnal variation of conductivity. However, the data for Rapid City indicate the early morning maximum noted at some places; thus those for October to November show a definite maximum at about 4^h local time, whereas those for June to July show higher values a few hours before and after that time.

The authors thank those individuals and organizations who worked with them—particularly the National Geographic Society and the United States Army Air Corps for aid in establishing and operating the station. G. L. Churchwell, Jr., acted as assistant observer during September to November, 1935.

[5]Terr. Mag., 36, 33-40 (1931).
[6]Carnegie Inst. Wash., Year Book No. 31, 250 (1932).

DEPARTMENT OF TERRESTRIAL MAGNETISM,
CARNEGIE INSTITUTION OF WASHINGTON,
Washington, D. C.

NOTES

(See also page 333)

15. *Portrait of Dr. Louis A. Bauer*—The custom of institutions of learning and research of honoring their founders and outstanding leaders by some suitable memorial was inaugurated at the Department of Terrestrial Magnetism of the Carnegie Institution of Washington on May 3, 1937, through a generous gift of Mrs. Louis A. Bauer and her daughter, Mrs. Robert W. Weeks. The memorial is a painting of Dr. Louis A. Bauer, the first Director of the Department, by Mrs. Leisenring of Washington. At the presentation, which took place in the Library of the Department, there were present, besides the Department staff, Dr. J. C. Merriam, President of the Carnegie Institution of Washington, Mrs. Bauer, Mrs. Weeks, and several invited guests.

In presenting the portrait, Mrs. Bauer made a few pertinent remarks regarding the important place occupied by Dr. Bauer in the founding and directing of the Department through a period of 25 years and of her desire to see a suitable portrait of him hung on the walls of the place he loved and in which he had labored so long and fruitfully.

Following Mrs. Bauer's presentation and the unveiling of the portrait by Mrs. Weeks, President Merriam accepted the painting on behalf of the Institution for the Department of Terrestrial Magnetism. He indicated the importance of having it as a part of the historical record of the science of terrestrial magnetism and its related researches. He pointed out the difficulties involved in such complex fields as those of the Department and stressed the long time required for the collection of data in the field and at observatories, for experimental researches in the laboratory, for interpretative discussions, and in solving the problems of those fields. He made eloquent reference to Dr. Bauer's initiative, far-reaching vision, and the fine structure of the Department's researches already built and building on the foundations so well laid.

Dr. Fleming, Director of the Department, then expressed to Mrs. Bauer and Mrs. Weeks the thanks of the members of the Department for the privilege of possessing the excellent likeness of the first Director, indicating the especial fitness that it find place in the Department not only to encourage those of its members who were privileged to work with him to maintain his high standard and ambitions for geophysical research but also to inspire them and those who may follow to carry on the work which he began.

16. *Giant-pulsation investigation in Iceland*—An expedition left Copenhagen, Denmark, July 21, 1937, for Iceland to obtain magnetic registrations for about three months to determine whether giant pulsations are still relatively frequent there and whether the registrations obtained simultaneously at two stations 12 to 15 km apart are identical during a giant pulsation. The work is in charge of Mr. Larsen who has been given a furlough by the Postmaster General of Denmark for the purpose. During the first two weeks he will be assisted by Dr. V. Laursen of the Danish Meteorological Office in setting up and adjusting the instruments. The registering equipment and assembled housings were tested at the Rude Skov Observatory in Denmark under field-conditions. This Expedition is sponsored by the Committee on Registration in Iceland of Giant Pulsations appointed at the meeting of the Association of Terrestrial Magnetism and Electricity of the International Union of Geodesy and Geophysics, at Edinburgh, in September 1936.

17. *Magnetic Observatory in Greece.*—We are glad to note from a report on magnetic measurements in Greece, presented by the Greek Geodetic Commission to the International Association of Terrestrial Magnetism and Electricity, that during the last ten years renewed activity in magnetic work has been in progress in Greece and that the establishment of a new observatory seems assured. The site is on the waste land between the village of Ménidi and the airport of Dékélia (Tatoi), and consists of 1500 square meters 1000 meters southwest of the nearest point of the aviation-base (latitude 38° 26′ north and longitude 23° 46′ east at elevation above sea-level of 230 meters).

The observation-house was completed in 1933 and toward the end of 1934, the standard Sartorius theodolite was installed and periodic observations, especially of declination, were made until the beginning of 1935. The National Observatory then made available the Mascart-type recording-instruments, which were installed in the north room of the Observatory. During 1935 some observations were obtained but it was found that they were influenced by changes of temperature which an attempt is being made to keep constant by rudimentary means. The observations made in 1936, both variation and absolute, were numerous and relatively satisfactory.

FURTHER STUDIES OF RADIO FADE-OUTS

By L. V. Berkner and H. W. Wells

Abstract—Observations during a radio fade-out by a comprehensive automatic multifrequency technique have yielded more detailed information concerning the nature of the effect. Data for the fade-out of July 31, 1937, are presented and analyzed for possible effects in the several regions of the ionosphere. It is concluded that there is no evidence of change in either the F_1- or F_2-regions. A slight increase in virtual height and maximum ion-density of the E-region is apparent just after the fade-out which is sufficient to account for the destruction in normal E-region reflecting boundary previously described. The evidence indicates that the effect occurs primarily below the 100-km level where the waves are absorbed because of an intense ionization in a region of high collisional frequency. Absorption of the ionization from the Sun responsible for the fade-out must be negligibly small in the F_1- and F_2-regions to account for the stability of these regions during the period of the fade-out.

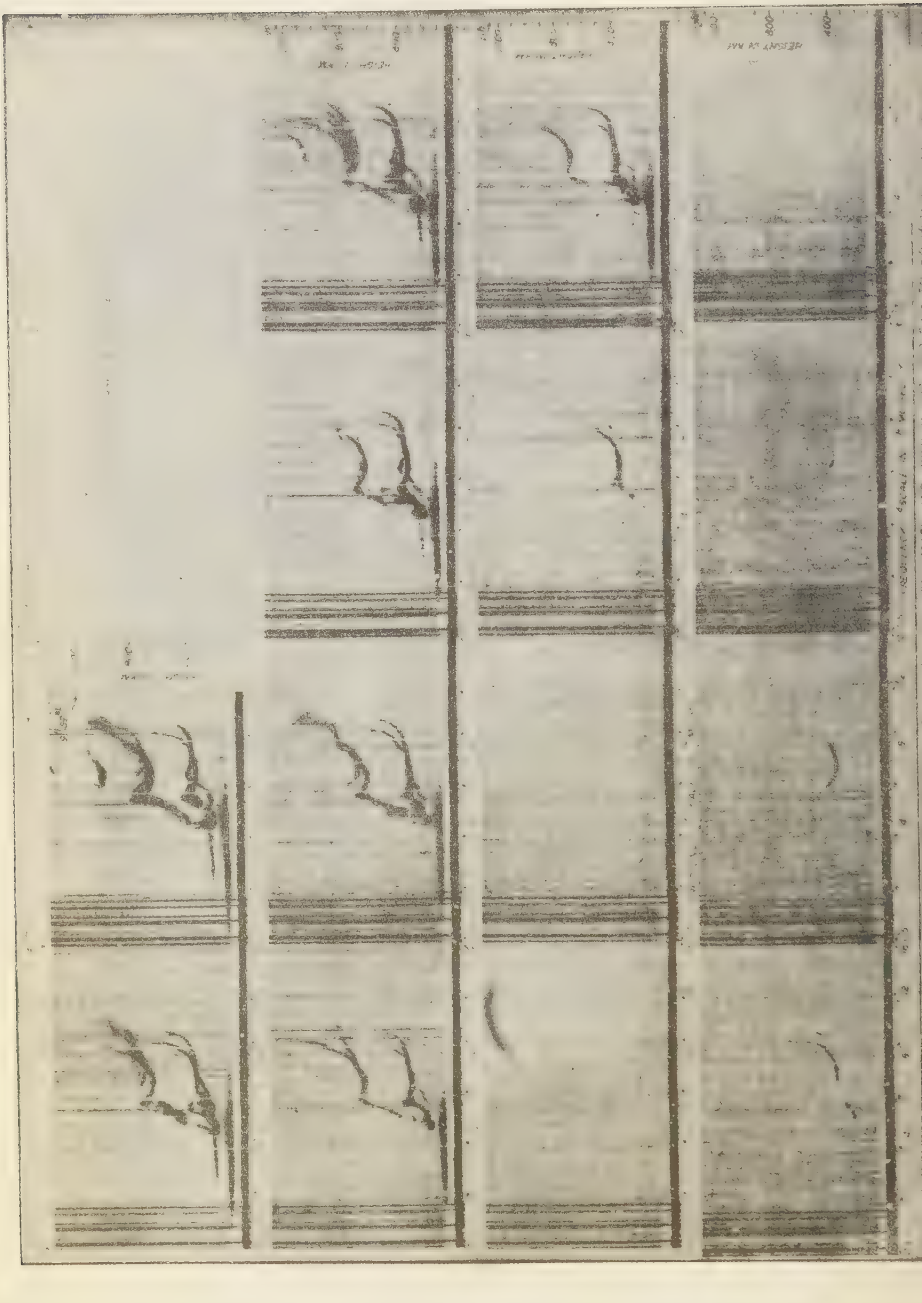
Since publication of the analysis of radio fade-outs observed at Huancayo and Watheroo magnetic observatories in the June issue of this Journal,[1] we have had the opportunity to observe the occurrence of this phenomenon using the automatic multifrequency technique of ionospheric investigation. This fade-out, of the type originally described by Dellinger,[2] occurred July 31, 1937, at about $11^h\,17^m$, 75° west meridian time with a mean duration of about $1^h\,47^m$, rendering it the longest intensity "3" fade-out which we have so far observed. The season and time of day were unusually favorable for observation of this effect. The method of observation is much more comprehensive than methods used heretofore and as a consequence a practically complete picture of the radio fade-out effect was obtained.

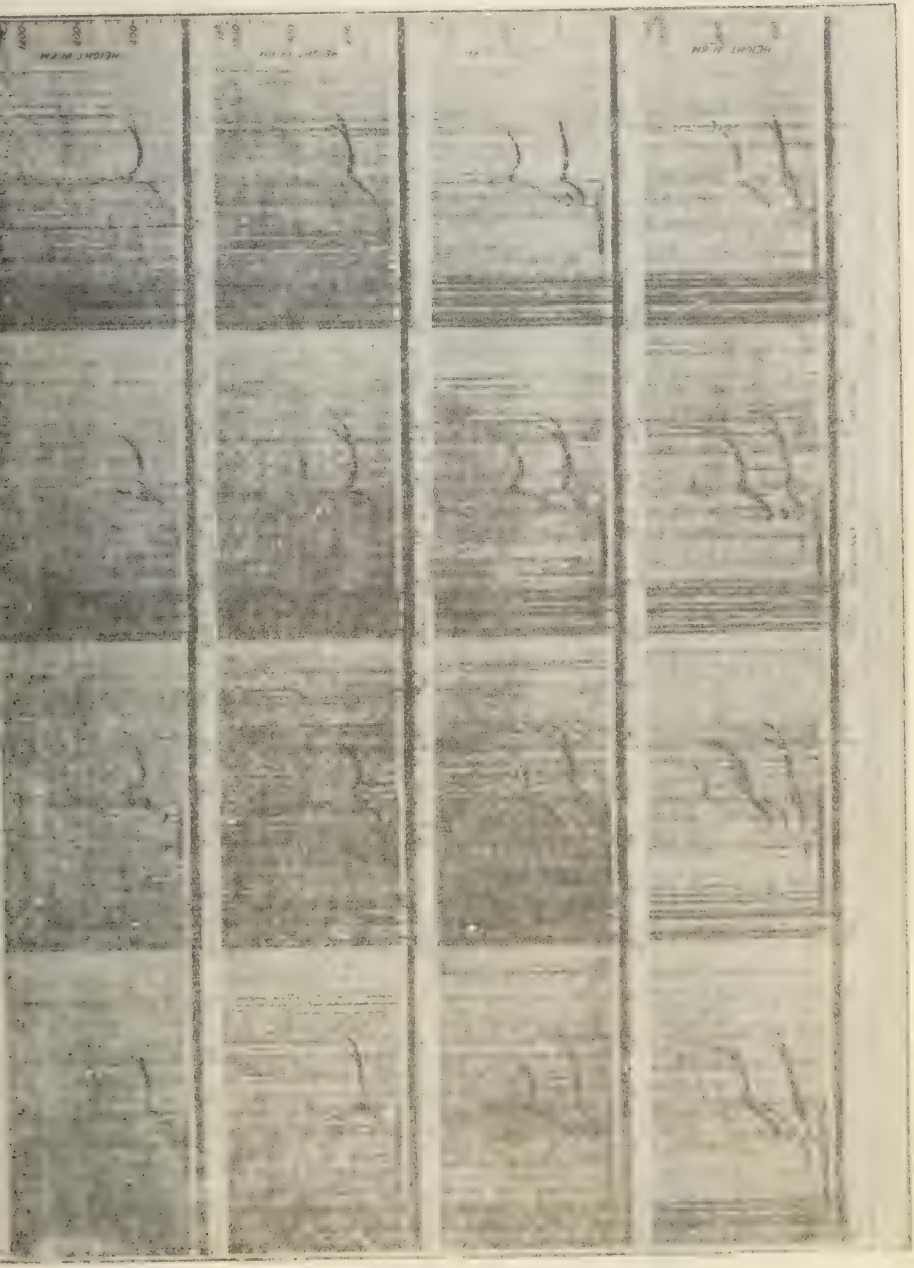
Observations were made at the Kensington Experimental Station, W3XFE, of the Department of Terrestrial Magnetism, Carnegie Institution of Washington (latitude 39° 01′ north, longitude 77° 05′ west). The equipment was of the automatic multifrequency type which has been developed at the Department of Terrestrial Magnetism for continuous registration of virtual heights of ionization throughout the ionosphere. Successive observations of virtual height are made automatically at exceedingly small increments of frequency over the range from 0.516 to 16.0 mc/sec. Each sweep through this frequency-range is completed in 15 minutes, four sweeps being made each hour. In this manner the virtual height of each ion-density in the range 3.1×10^3 to 3.1×10^6 equivalent electrons per cc is measured,[3] and from the curves thus formed on the photographic trace, the critical frequency, minimum virtual height, and other characteristics of each region are determined.

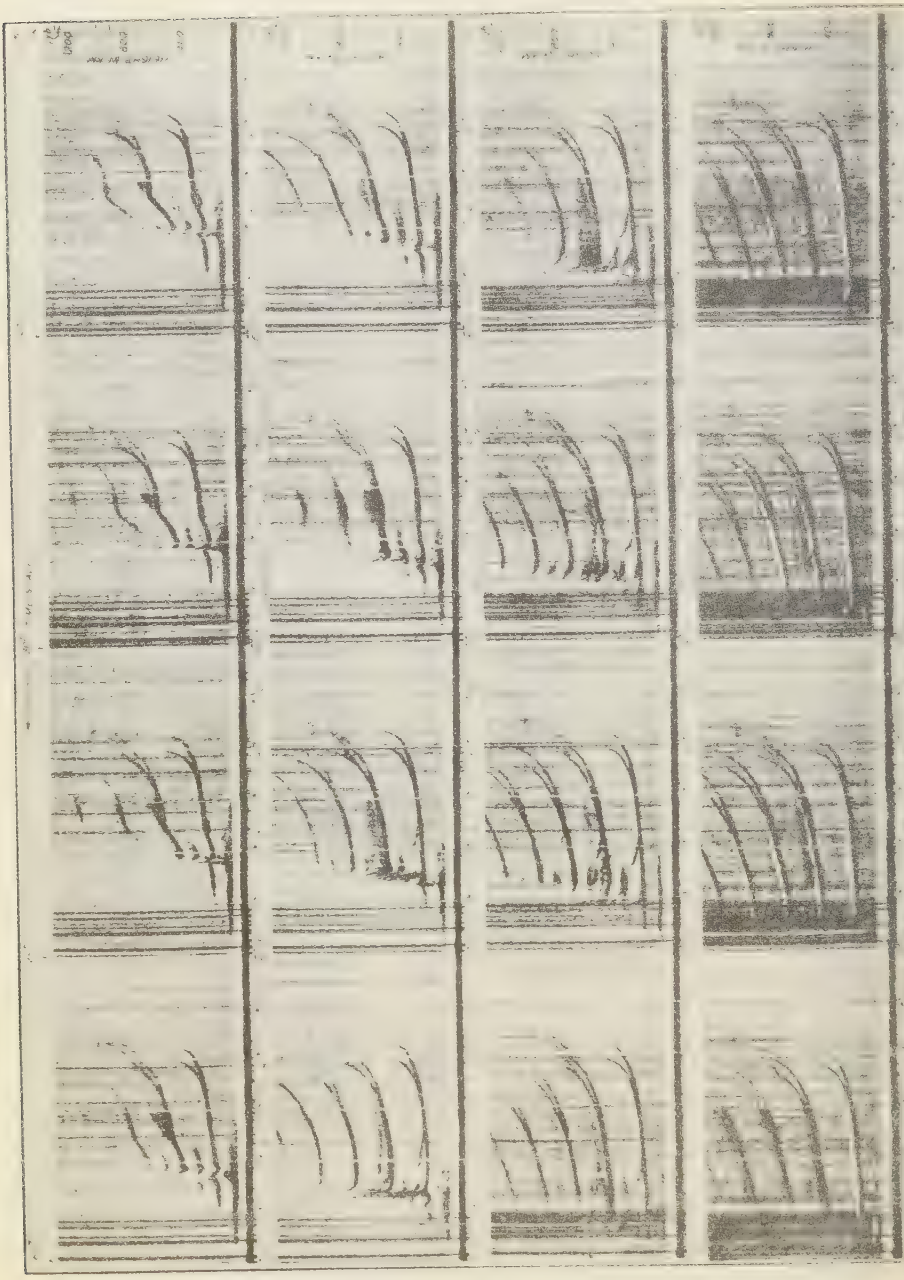
A series of such photographic records is illustrated in Figures 1*A*, 1*B*, and 1*C* for the hours between $9^h\,30^m$ and $21^h\,00^m$, 75° west meridian time, July 31, 1937. The base-line consists of thousands of pulses of about 100-microseconds duration on frequencies beginning at 16.0 mc/sec and spaced at small increments of frequency down to 0.516

[1] L. V. Berkner and H. W. Wells, Terr. Mag., **42**, 183-194 (1937).
[2] Science, **82**, 351 (1935); Phys. Rev., **48**, 705 (1935); Terr. Mag., **42**, 49-53 (1937).

[3] The number of electrons per cc required to reflect the "o" wave-component of a given frequency at normal incidence is given by $N=1.24\times10^4 f^2$ where f is given in mc/sec.







mc/sec. The reflections from each transmitted pulse are recorded along the vertical scale which is appropriately calibrated in virtual height as determined from the time for the pulse of waves to travel to the reflecting stratum and return. Because successive reflections from a given region form a coherent trace on the record, the resultant curves appear continuous as contrasted with the incoherent spots of interference and noise which are scattered on the trace in a random manner and therefore appear only as fogging on the record. This is accentuated from 15^h to 17^h where the trace is darkened during local thunderstorm-conditions.

Certain discontinuities on the curves represent critical frequencies, namely, the frequencies at which the wave just penetrates given regions and from which the maximum ion-densities of the regions can be readily calculated. Near each critical frequency the reflection-pattern is resolved into two components, termed the "o" and "x" wave-components, and representing what may be called a Zeeman effect due to the presence of the Earth's magnetic field in the ionosphere. Because the "o" wave-component is, in general, most penetrating, it can be identified on the records becoming critical at the lower frequency. The absorption for the "x" wave-component is the greater in the magnetic latitude of Washington. Therefore this wave-component is often either weak or not recorded. Calculation of the ion-density from the "o" wave-component at normal incidence is unaffected by the presence of the Earth's magnetic field. It is therefore convenient to represent most of the features of the ionosphere from this wave-component. Because the upward radiation of the equipment and the receiver-sensitivity are quite uniform on all frequencies, the lowest frequency on which reflections are observed forms a relative measure of the absorption in the lower ionosphere. These factors together with the minimum virtual height form the principal criteria for comparison of successive ionospheric measurements.

These data are plotted graphically in Figure 2 for each 15-minute interval during July 31, 1937, and represent the most complete ionospheric information assembled during any 24-hour period. In addition, the hourly mean values for the 6-day period July 26-31, 1937, are given by dashed lines for purpose of comparison. Each hourly mean value comprises four values determined during the hour on each of the six days involved in the mean.

The nature of the fade-out effect is quite apparent from an examination of Figures 1 and 2. This fade-out coincided with a bright chromospheric eruption of intensity 3 observed at both the Mount Wilson Observatory and the Huancayo Magnetic Observatory. The following description of the eruption has been furnished us by Dr. Richardson of the Mount Wilson Observatory.

"An eruption of intensity 3 was first photographed by us at 11^h 12^m (75° west meridian time) over a large spot-group at 23° north, 67° east. We have no earlier observations of this region, so the time of commencement is unknown; but as the flocculi were increasing in brightness when first seen, it might be estimated that the outburst began about 11^h. Maximum brightness was at about 12^h 04^m with the end occurring in the neighborhood of 12^h 30^m. The eruptive flocculi covered an unusually large area."

The maximum brightness of the eruption coincided very nearly with the central time of the fade-out. Simultaneity of these events offers

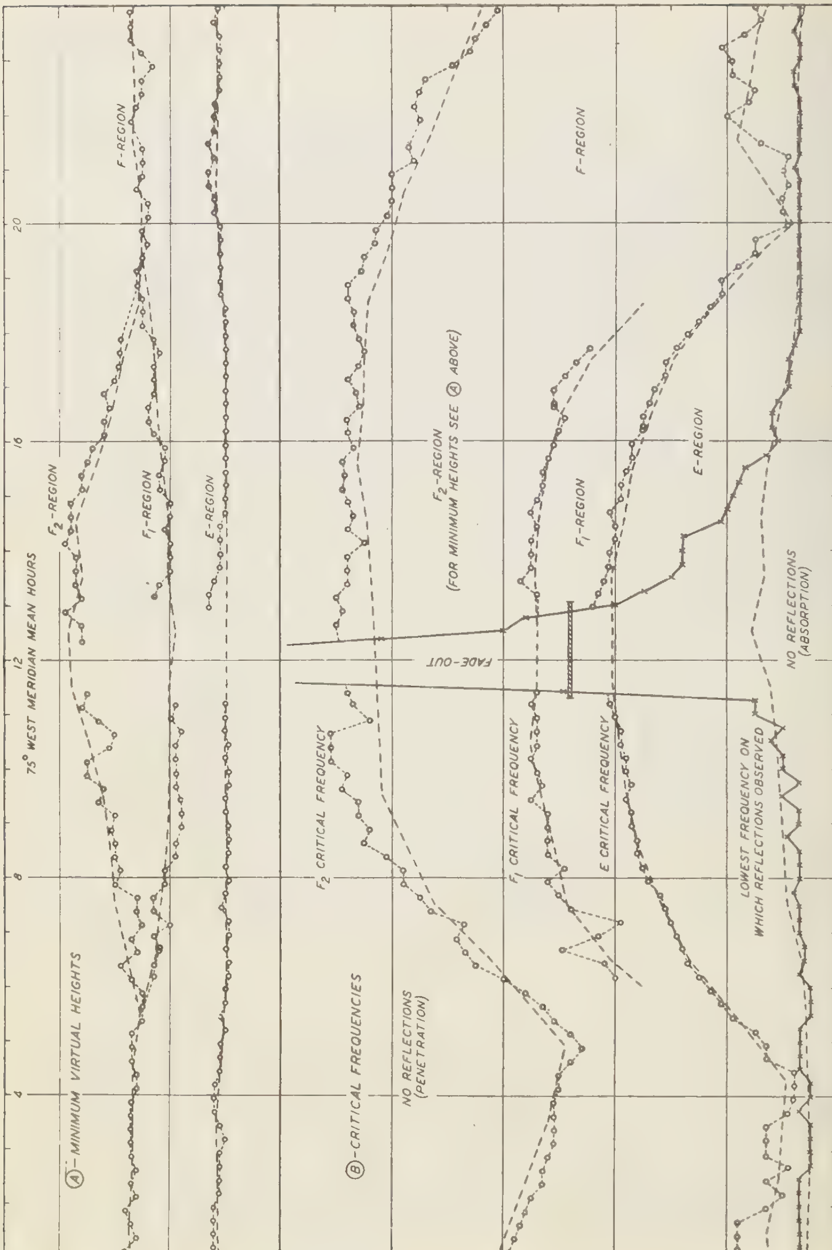


FIG. 2—THE IONOSPHERE SHOWING RADIO FADE-OUT JULY 31, 1937, DETERMINED FROM AUTOMATIC MULTIFREQUENCY REGISTRATIONS, KENSINGTON, MARYLAND, (39°01' NORTH, 77°05' WEST)

LEGEND: -o-o-o OBSERVED VALUES FOR "O"-WAVE COMPONENT; - - - - WEEKLY MEAN OF VALUES FOR "O"-WAVE COMPONENT (JULY 26 TO 31, 1937); ——— LOWEST

further support to Dellinger's hypothesis that fade-outs are associated with bright chromospheric eruptions.

The fade-out was also observed at the Huancayo Magnetic Observatory on the fixed-frequency ionospheric records obtained on 4.8 mc sec with intensity 3 between $11^h\ 17^m$ and $13^h\ 04^m$. These widely separated observations attest to the widespread character of the effect.

The effect is first evidenced on the record commencing at $11^h\ 15^m$ where absorption has increased so that the multiple reflection is absent and the reflection-intensity is generally diminished. At $11^h\ 23^m.5$ reflections disappear entirely at a frequency of 4.9 mc sec. During the subsequent three records, no reflections are observed on any frequency. The record commencing at $11^h\ 30^m$ is of particular interest because of the complete absence of atmospherics and interference on the higher frequencies down to about 12.0 mc sec, indicating a cessation of high-frequency wave-propagation through the ionosphere at all angles of incidence. Lower-frequency noise and signals which are transmitted an appreciable distance along the ground are not so materially diminished on the traces.

The manner in which the reflections reappear with respect to frequency at the termination of the fade-out is of the utmost importance to an understanding of the nature of the effect. On the record commencing at $12^h\ 15^m$ (see Fig. 1) only the higher frequencies (above 6.0 mc sec) are in evidence. As time progresses, reflections are returned from transmissions on successively lower and lower frequencies until the entire reflection-pattern becomes quite normal by $15^h\ 45^m$.

The quantitative nature of the effect is much more apparent from Figure 2, where the interval of fade-out is outlined by the limiting frequencies returning reflections. It is at once evident that the duration of the fade-out at normal incidence is dependent upon the observing frequency, and as a consequence it will also depend somewhat upon the output-power of the transmitter and the receiver-sensitivity.

Examination of the curves for F_1-region and F_2-region critical frequencies shows that at the onset of the effect there is no significant change in critical frequency and that when reflections reappear, the critical frequencies have not deviated from the normal trend in the least—in fact the fluctuations are rather smaller than often observed around the same hours on preceding and following days. There does, however, appear to be a small but significant increase in the E-region critical frequency apparent immediately after the fade-out. Assuming this to be a result of the effect of fade-out, equilibrium-conditions in the E-region are not immediately reestablished at the end of the fade-out. Equilibrium-conditions would be reached still more slowly in the upper regions because of decreasing atmospheric density with height. One can reasonably suppose, therefore, that had any increase in ion-density occurred in the upper regions, it would either become apparent at the onset of the effect or a small residual increase in critical frequency of these regions would persist through the termination of the fade-out on high frequencies. The absence of any such increase coupled with the fact that unchanged values of F_1-region and F_2-region critical frequencies are observed long before the end of the effect on the lower frequencies leads to the conclusion that no appreciable change has occurred in the maximum ion-densities of the F_1- and F_2-regions during the fade-out.

In considering the lowest virtual heights of each region, it is found that no significant change has occurred for the F_2-region. As concerns the F_1-region, a small increase in minimum virtual height is observed, but we believe this to be due entirely to the increase in E-region critical frequency and not to a change in the region itself. As illustrated in Figure 3, a small increase, $\triangle f$, in the E-region critical frequency may render the lower portion of the F_1-region invisible. As a consequence,

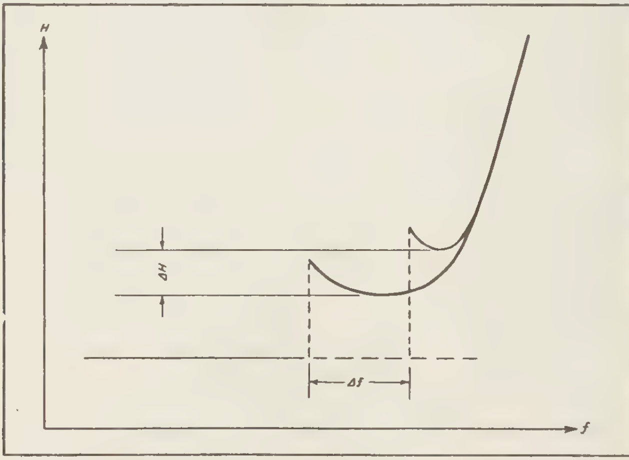


FIG. 3—DEPENDENCE OF F_1-REGION VIRTUAL HEIGHT ON E CRITICAL FREQUENCY

there may be a small increase in observed minimum virtual height, $\triangle H$, though it occurs solely because the lower part of the F_1-region is masked. A close inspection of the data shows that this is the case directly after the fade-out; it is doubtful, therefore, if any actual change in virtual height of this region has occurred. This view is supported by examination of more than 200 fade-outs as observed during fixed-frequency recording under such circumstances that the F_1-region virtual height would be unaffected by small changes in E-region ionization.

The change in virtual height of the E-region cannot be so explained. The data indicate therefore that of the three ionospheric regions, only the E-region shows an appreciable effect—namely, an increase in ionization and virtual height. This change is sufficient to account for the destruction of the E-region reflection-boundary discussed in the previous paper[1]. The change in the E-region near the level of maximum ion-density cannot alone explain the phenomenon of echo-disappearance. The data of Figures 1 and 2 show that the fade-out effect is perceptible on the lower frequencies more than two hours after the E-region appears quite normal. Thus the effect predominates below E-region levels. This supports the view that the fade-out occurs as a consequence of an increase in ionization in a region of high collisional-frequency below the E-region, where the wave is absorbed.

If we assume the output-radiation of the transmitter and the receiver-sensitivity to be uniform on all frequencies (which is very nearly the

case) and the termination of radiation from the bright chromospheric eruption to be abrupt, the curve for lowest frequency on which reflections are returned is then a function of the rate of decrease of ionization in the absorbing region. This suggests that an analytical examination of a number of curves obtained by this method should lead to more quantitative ideas concerning the nature of this absorbing region.

While magnetic effects are often associated with intense fade-outs,[4] reports indicate that no significant magnetic change was observed at the Huancayo, Cheltenham, or Mount Wilson observatories. This suggests that the ionization produced during this fade-out was not sufficiently intense to cause a magnetic effect. From the radio data alone it has as yet been impossible, however, to distinguish any difference between fade-outs associated with magnetic effects and those not so accompanied. This point will bear further examination. It may be possible eventually with the present more powerful methods to so distinguish.

In summarizing the result of this investigation, we find that multifrequency observation confirms and extends the conclusions already drawn as to the nature of the fade-out from the fixed-frequency data. The duration of the fade-out as observed at normal incidence is an inverse function of the frequency of measurement. The commencement is not quite immediate on all frequencies, so that the time of commencement may appear slightly different to different observers, depending upon the transmitter-frequency, power, and location with respect to the sub-solar point. There is nothing in the data to indicate that any change occurs in either the virtual height or maximum ion-density of the F_1- and F_2-regions during the fade-out. When the time required for establishment of equilibrium-conditions is considered for the several regions it seems probable that no change in the F_1- or F_2-regions has occurred. A small increase in ion-density and virtual height of the E-region which appears significant is observed. This is sufficient to account for the destruction of the normal E-region reflection-boundary previously described. Abnormal absorption of the wave continues after the E-region conditions return to normal, confirming the view that absorption occurs below the level of maximum E-region ionization. It seems probable therefore that the intense ionization causing the fade-out occurs predominantly below the 100-km level, the effect extending up into the E-region only slightly. The absorption of the ionizing radiation from the Sun, producing the fade-out must be negligibly small in the F_1- and F_2-regions to account for the stability of these regions during the fade-out.

We wish to acknowledge our debt to Dr. J. A. Fleming, who has encouraged and supported the development of the multifrequency equipment and installations, to F. T. Davies, Observer-in-charge, W. E. Scott and H. E. Stanton, who conducted the complimentary observations at the Huancayo Magnetic Observatory, and to Dr. R. S. Richardson of the Mount Wilson Observatory for his description and data concerning the solar effects accompanying this fade-out.

[4]J. A. Fleming, Terr. Mag., **41**, 404-406 (1936); A. G. McNish, Nature, **139**, 244 (1937); Terr. Mag. **42**, 109-122 (1937); Phys. Rev., **52**, 155-160 (1937).

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LETTERS TO EDITOR

PROVISIONAL SUNSPOT-NUMBERS FOR JUNE TO AUGUST, 1937

(Dependent alone on observation at Zürich Observatory and its station at Arosa)

Day	June	July	August
1	*M*79[c]	69[a]	...
2	89[d]	*E*91[c]	180[a]
3	92	74	*M*207[c]
4	116[bd]	*M*65[cd]	197[d]
5	*W*128[c]	91	205[ab]
6	121	*E*108[cd]	176
7	102	143[a]	135
8	64[a]	*W*185[cd]	154[d]
9	*E*73[cd]	181[bd]	173
10	98[add]	192	183[a]
11	96	*W*202[ac]	140
12	*ME*134[acc]	223[ad]	*M*144[c]
13	*E*166[c]	188[a]	114
14	185	215[aad]	124[ab]
15	191[ad]	204[a]	128
16	*M*174[abcd]	...	119
17	190[b]	152[d]	...
18	194[a]	167[b]	82[dd]
19	185	155[a]	*E* 88[c]
20	183[a]	*E*149[c]	*E* 96[c]
21	186[d]	150	80
22	199[ad]	145[d]	103
23	*M*163[ac]	139[a]	*E*139[ac]
24	133	126	*M*150[ca]
25	108	124	137[ab]
26	116	115[d]	144
27	91[b]	143[d]	143[d]
28	80[a]	124[b]	130
29	*E*80[c]	*E*128[bc]	110
30	93	139[d]	109[d]
31		131	128
Means...	130.3	143.9	138.6
No. days	30	30	29

Mean for quarter April to June, 1937: 130.4 (90 days)

[a]Passage of an average-sized group through the central meridian.
[b]Passage of a large group or spot through the central meridian.
[c]New formation of a group developing into a middle-sized or large center of activity: *E*. on the eastern part of the Sun's disc; *W*. on the western part; *M*. in the central-circle zone.
[d]Entrance of a large or average-sized center of activity on the east limb.

EIDGEN. STERNWARTE,
Zürich, Switzerland

W. BRUNNER

SOLAR DISTURBANCE OF MAY 25, 1937, ACCOMPANIED BY SIMULTANEOUS MAGNETIC, EARTH-CURRENT, AND IONOSPHERIC EFFECTS

Solar—On May 25, from $16^h\,51^m$ to $17^h\,05^m$ GMT, a bright active flocculus was observed on the Sun at latitude 19° south and longitude 50° west from the central meridian.

Magnetic—The horizontal-intensity component H increased 118 gammas between $16^h\,51^m$ and $17^h\,01^m$, then decreased less rapidly to normal value by $17^h\,20^m$. The declination decreased one minute of arc during this interval and returned to normal value. The vertical-intensity component Z increased 3 gammas and then decreased 15 gammas between $16^h\,52^m$ and $17^h\,05^m$.

Earth-current—All four earth-current lines showed sharp changes in voltage at the same time as the solar disturbance.

Ionospheric—The continuously recording ionospheric record on 4800 kilocycles showed a complete fade-out during $16^h\,55^m$ to $17^h\,14^m$.

F. T. DAVIES, W. E. SCOTT, H. E. STANTON
HUANCAYO MAGNETIC OBSERVATORY,
Huancayo, Peru, June 3, 1937

PROVISIONAL SOLAR AND MAGNETIC CHARACTER-FIGURES, MOUNT WILSON OBSERVATORY, APRIL, MAY, AND JUNE, 1937

Greenwich mean time						Range hor. int.
Beginning			Ending			
1937	h	m	d	h	m	γ
Apr. 12	8	52	13	02	..	102
Apr. 24	12	01	28	24	..	272
May 4	16	55	5	17	..	173
June 5	18	..	7	02	..	103
June 22	9	55	22	24	..	86
June 27	2	46	..	..	..	...

The magnetic storm from April 24 to 28 could be described as a series of three storms separated by quiescent periods lasting a few hours. The second active period began suddenly at $15^h\,47^m.5$, April 25, the third at 18^h, April 26. During these storms two sunspot-groups were very active. The smaller one crossed the central meridian on April 23.3 in latitude 24° north, the larger on April 24.7 in latitude 19° north.

The storm of June 5 was probably caused by activity in the group which crossed the central meridian on June 4.8 in latitude 13° north.

When the storm of June 22 began two active groups were near the central meridian, the preceding crossing it on June 21.1 in latitude 12° north, the following on June 22.9 in latitude 11° north. The polarities in the following group were reversed.

The most active group on the Sun during the moderate magnetic storm of June 27 crossed the central meridian on June 27.0 in latitude 12° south. The total range of the storm and the time it ended are unknown because of an incompleteness in the records.

Day	April 1937 K_2 A	K_2 B	$H\alpha B$ A	$H\alpha B$ B	$H\alpha D$ A	$H\alpha D$ B	No. groups	Mag'c char.
1	3	3	3^d	3	4	1	13	0
2	....	....	....	....	....	....	13	0.5
3	....	....	....	....	....	....	12	0.5
4	3	3	3	3	3	3	11	0
5	3	3	3	3	3	1	10	0
6	3	3	3	3	3	1	10	0
7	3	3	3	3	3	1	9	0
8	3	3	3	3	3	1	9	0
9	3	3	3	3	3	1	7^h	0
10	3	3	3	3	2	2	6	0
11	2	2	2^d	2	2	2	6^b	0.5
12	3	1	3	1	2	2	6	1
13	2	1	2	1	2	1	6	0.5
14	2	1	2	1	3	1	2	0
15	....	....	....	....	....	....	5	0
16	....	....	....	....	....	....	5	0
17	3	3	3	3	2	1	7	0
18	3	2	3	2	3	2	10^b	0.5
19	3	2	3	2	3	3	11^b	0
20	3	3	3	3	3	2	10	0
21	3	3	3^d	3^c	4	3	9	0.5
22	3	3^c	3^d	3	3	2	7^e	0
23	4	4	4	4	4	3	7^i	0
24	4	4	4^d	4^c	4	3	9^{a,i}	1.5
25	4	4	4^d	4^c	4	4	11^b	2
26	4	3	4	3	4	4	9	2
27	3	3	4^d	3	5	4	8	1.5
28	....	....	....	....	....	....	8	2
29	3	2	3^d	2	5	3	7^h	0.5
30	2	3	3	3^c	5	3	7	0.5
31								
Mean	3.0	2.7	3.1	2.7	3.3	2.2	8.3	0.5

Day	May 1937 K_2 A	K_2 B	$H\alpha B$ A	$H\alpha B$ B	$H\alpha D$ A	$H\alpha D$ B	No. groups	Mag'c char.
1	2	2	3^d	1	4	4	6	0
2	3	2	3^d	2	4	3	7	0
3	3	3	3	2	3	2	5	0
4	2	2	2	2	2	3	5	0.5
5	3	3	2	3	2	2	5	1.5
6	2	3	2	2	2	2	4	0
7	2	2	2	2	3	1	5	0
8	3	1	3	2	3	1	7	0
9	3	2	3	2	4	2	9	0.5
10	3	3	3	3	4	0	10	0.5
11	3	3	3	3	4	1	8	0.5
12	3	3	3^d	3	4	2	·8	0
13	3	2	3	2	4	1	10	0
14	3	3	3^d	3	4	3	11	0.5
15	3	2	3	3	3	2	11^i	0
16	4	3	4^d	3	4	2	13^a	0.5
17	4	3	4^d	3^c	4	2	10	0
18	4	3	4^d	3^c	3	3	10	0
19	4	4	....	....^c	....	....	13^h	0.5
20	5	4	4	4^c	3	3	15^{a,g}	0
21	5	4	5	4	3	2	12^{h,i}	0.5
22	....	....	....	....	....	....	....	0.5
23	4	4	4^d	4	3	2	12	0
24	4	3	4^d	3	3	2	11	0
25	....	....	....	....	....	....	9	0.5
26	4	4	4	4	3	3	9^h	0.5
27	3	4	3	4	3	2	8^g	0.5
28	3	3	3^d	3	4	4	6^b	1
29	3	2	3	2	3	3	7	0.5
30	3	2	3	2	3	2	6^h	0
31	3	2	4	4^c	3	2	7^a	0
Mean	3.2	2.8	3.2	2.8	3.3	2.2	8.6	0.3

Day	June 1937 K_2 A	K_2 B	$H\alpha B$ A	$H\alpha B$ B	$H\alpha D$ A	$H\alpha D$ B	No. groups	Mag'c char.
1	3	2	3^d	2	3	2	7	0
2	3	1	3^d	1^c	3	2	7	0
3	3	2	3	3	3	2	7	0
4	3	3	3	3	3	2	10^a	0.5
5	3	3	3	·3^c	3	2	10	0.5
6	3	3	3^d	3	3	3	6	1
7	3	3	3	3	3	3	9	0
8	4	4	4	4	4	3	7	0
9	4	4	4^d	4^c	3	3	8^g	0
10	4	4	4^d	4^c	3	2	9^a	1
11	4	4	4	4	3	1	10	0
12	4	3	4^d	·3	3	2	11^b	0
13	4	3	4^d	3	3	2	12	1
14	....	....	....	....	....	....	14	0.5
15	5	5	5	·5^c	3	2	9^f	0
16	5	5	5	5^c	3	3	12^{a,h}	0.5
17	5	5	5	5^c	3	3	11	0.5
18	5	5	5	5	3	3	13^h	0
19	5	4	5	4	3	3	13	0
20	4	3	4^d	3^c	3	3	12	1
21	4	4	4	4	3	1	11^f	0.5
22	....	....	4	4	4	1	14^f	1
23	4	4	4^d	3	4	3	12	0
24	....	....	4^d	3	4	4	12	0.5
25	....	....	3	3	3	4	8	0.5
26	....	....	3	4^e	3	3	9	0
27	3	4	4	4^c	4	4	7^g	1
28	....	....	....	....	....	....	9^b	....
29	3	3	3^d	3	3	2	7	0
30	3	3	3	3	4	2	7	0
31								
Mean	3.8	3.5	3.8	3.5	3.2	2.5	9.8	0.3

NOTE—For an explanation of these tables see this JOURNAL, 35, 47-49 (1930). The character-figures of solar phenomena are estimated from the spectroheliograms which are made with a 2-inch solar image, usually in the early morning. The very bright chromospheric eruptions are reported in these notes if observed at any time during the day.

?Indicates an uncertain value which should be given low weight.

a, b Formation of a new group which later developed to average size or larger; (a) less than 30° from the center of the disc, (b) more than 30° from the center of the disc.

Several active groups crossed the central meridian between June 15.6 and June 18.0 without causing any magnetic storm.

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Seth B. Nicholson
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THE GEOPHYSICAL OBSERVATORY OF CHAMBON-LA-FORÊT

The development of electric-railway lines, particularly in the vicinity of large cities, has made necessary in recent years the transfer of several magnetic observatories to more isolated and magnetically undisturbed sites. Thus in the last decade it has been found necessary to move the principal magnetic observatory of Germany from Seddin to a new site at Niemegk and the Sverdlovsk (formerly Ekaterinburg) Observatory, where for nearly 100 years magnetic observations had been in progress, to Vyssokaja Dubrava, some 30 km from the old location.

We now learn from a booklet kindly furnished us by Professor Ch. Maurain, that the central magnetic observatory of France, previously located at Val-Joyeux, about 25 km from Paris, owing to the encroachment of industrial electric currents, has been moved to a clearing in the Forest of Orléans, Commune de Chambon-la-Forêt (Département du Loiret), 87 km south of Paris. The geographical coordinates of the new observatory are latitude 48° 01′ 26″ north, longitude 2° 15′ 36″ east of Greenwich, or 0° 04′ 38″ west of Paris; the elevation above sea-level of the pier where the magnetic observations are made is about 133 meters. The greater part of the site lies in a clearing in the forest, the remainder being wooded. A determination of the magnetic susceptibility of several samples of the soil gave a mean value of 2×10^{-6}, so that the soil may be regarded as practically non-magnetic.

The main building contains the offices, laboratories, and quarters for the resident staff. On the grounds are four huts, two for magnetic and two for electric measurements, the former containing no iron or magnetic materials.

The observatory of Chambon-la-Forêt is intended to replace that of Val-Joyeux, which was devoted to the study of terrestrial magnetism and atmospheric electricity. The two other observatories belonging to the Institut de Physique du Globe of the University of Paris will continue their work, namely: Observatory of Parc Saint-Maur seismology, meteorology, actinometry, and phenology; Observatory of the Petit Point, at Nantes—magnetism and meteorology. The Observatory of Chambon-la-Forêt has been established on a grander scale than that of Val-Joyeux; its offices, laboratories, and two spare-rooms permit visiting investigators to remain for considerable periods.

Regular magnetic measurements were begun January 1, 1936, under the direction of M. L. Eblé. They consist of absolute determinations once a week (horizontal component, declination, and inclination) and photographic registration of the variations (horizontal force, vertical force, and declination) by Mascart and la Cour variometers. The registration of the Mascart instruments is controlled by direct readings three times per day. Measurements of inclination will be made principally with a Cambridge inclinometer, but observations will also be obtained with a Brunner dip-circle. Declination and horizontal force are measured

with a Brunner-Chasselon magnetic theodolite but a Smith coil-magnetometer of the Cambridge Instrument Company will soon be put into operation. The absolute measurements and the registrations have been continued at Val-Joyeux so that the long series of magnetic results there may be overlapped by more than a year, thus assuring the continuity of the series.

The regular atmospheric-electric work at Val-Joyeux will be continued at Chambon including potential-gradient, conductivity, and ionization (number of large and small ions). The necessary apparatus has been put into condition by M. E. Salles and will soon be installed. It is also proposed to make investigations of earth-currents and of the induction in a horizontal loop produced by the variations of the magnetic vertical component. In addition regular meteorological observations supplementary to the atmospheric-electric measurements will be made. The site of the new Observatory, in an almost level plain in the midst of a large forest, will impart to these observations a special interest.

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H. D. Harradon

OBSERVATIONS AT SECULAR-VARIATION STATIONS IN MEXICO DURING APRIL AND MAY, 1937

During April and May 1937, R. O. Sandoval of the Magnetic Section of the National Astronomical Observatory of Mexico made observations of the absolute values of the magnetic elements at Oaxaca and Puebla. The results of these observations are shown in Table 1. Mr. Sandoval's instrument was CIW-type magnetometer-inductor No. 107 manufactured by the Precise Instrument Company, and the values shown in the Table are corrected to International Magnetic Standards.

Table 1—*Magnetic elements at secular-variation stations in Mexico*

Station	Latitude, north	Longitude, west	Altitude	Date	LMT	Declination east	LMT	Inclination north	LMT	Horizontal intensity
	° ′	° ′	*meters*	1937	*h m*	° ′	*h m*	° ′	*h m*	γ
Oaxaca	17 05.0	96 42.7	1550	Apr. 28	.. ..	....	7 03–		.. ..	.....
						.....	17 38[a]	44 09.0	.. ..	.....
				29	8 26	9 14.9	6 56	44 09.7	9 03	3149
					9 03	9 13.6	.. ..	.. ....	.. ..	.....
					9 28	9 13.6	.. ..	.. ....	.. ..	.....
				30	6 53–		.. ..	.. ....	7 05–	
					15 16[a]	9 07.4	.. ..	.. ....	15 29[a]	3148
				May 2	6 37–		.. ..	.. ....	.. ..	.....
					17 33[a]	9 12.0	.. ..	.. ....	.. ..	.....
Puebla	19 02.5	98 11.2	2475	May 5	8 55	9 31.7	7 10	46 36.2	9 20	3111
					9 20	9 29.1	.. ..	.. ....	.. ..	.....
				6	7 48	9 33.2	7 35	46 40.7	8 29	3107
					8 29	9 34.2	.. ..	.. ....	.. ..	.....
					8 54	9 35.2	.. ..	.. ....	.. ..	.....

[a]Diurnal-variation series.

At Oaxaca the station is at the airport 2.5 km from the Cathedral, 150 meters northwest of the north end of the hangar and four meters east of road to farm. It is marked by a wooden peg. True azimuths from south through west are: Cross, Merced Church, 34° 11′.2; cross Santo Domingo Church, 52° 18′.3.

At Puebla the station is at the airport one km east of the Cathedral, 200 meters southeast of the tower of the semaphore and 30 meters southeast of the upper part of the letter P of the name Puebla. True azimuths from south through west are: Cross, north tower Cathedral, 134° 17′.6; cross El Alto Church, 181° 54′.9.

Observatorio Astronomico Nacional, Joaquín Gallo, *Director*
Tacubaya, D. F., Mexico, January 22, 1937

MACGREGOR ARCTIC EXPEDITION, 1937-38

This Expedition, under the command of C. J. MacGregor, Meteorologist of the United States Weather Bureau, left Port Newark, New Jersey, for the Far North on July 1, 1937. The Expedition hopes to arrive in Grinnell Land late in August and will establish its base at Fort Conger, Lady Franklin Bay, a station which was previously occupied by General A. W. Greely during the First International Polar Year in 1882-83. On August 17 the Expedition reported by radio being in latitude approximately 73° north near Thule, Greenland.

Commander MacGregor with eleven assistants sailed on the three-masted schooner, *General A. W. Greely*. This schooner of 200 tons net registry was built for trading in the arctic regions. Her frame is extra strong and the massive knees to withstand ice-pressure are all of natural wood. In addition her hull is encased by two extra sheaths of two-inch planking of oak. Sails will be depended upon during the greater part of the voyage to the north, occasional assistance being given by two 40-horse-power Sterling marine engines. The twin propellers are protected from small pieces of ice by heavy oak-casings.

The Expedition is well provisioned—though Commander MacGregor hopes to return in September 1938, food-stores sufficient for two years were taken as well as emergency-rations for a third year. The cargo weighs nearly 250 tons and includes a wide assortment of supplies including building material for three buildings, a Waco airplane, 15 cylinders of hydrogen, 15 tons of coal, 60 fifty-gallon drums of gasoline, a 5-kilowatt generator set, and a 110-volt storage-battery.

The Expedition is not planned on spectacular lines. Commander MacGregor hopes, however, to execute a full program of scientific work and bring back solid results. Through the cooperation of the United States Weather Bureau, an extensive meteorological program is assured. A complete weather-station will be operated at the base. Upper-air work will be stressed with at least two balloon-flights daily supplemented by airplane-flights. Thirty radio-sondes have also been taken. Two complete weather-reports will be radioed daily to the Weather Bureau in Washington.

In the field of the Earth's magnetism the Carnegie Institution of Washington, through its Department of Terrestrial Magnetism has made possible the establishment of a complete magnetic observatory. A magnetograph will record continuously declination, horizontal intensity,

and vertical intensity with regular control by absolute observations. Weekly reports of magnetic activity will be radioed to Washington to furnish additional data for the American character-figure. Detailed reports of magnetic storms will be furnished. R. Fitzsimmons will give full time to the magnetic program, being assisted when necessary by Commander MacGregor. As complete as possible reduction of the magnetic records is contemplated.

The Expedition is planning to make continuous visual observations on the occurrence and intensity of the aurora borealis. Simultaneous photographs of auroras will be taken at two stations with cameras kindly loaned by Professor Störmer. Intercommunications between the stations will be maintained by radiophone. Two complete 7½ meter transmitters have been taken. An innovation in arctic procedure is the provision of two wind-driven generators for charging the storage-batteries used for the transmitters at the field-stations. Through the cooperation of the Eastman Kodak Company films in color of the aurora borealis will be attempted.

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H. F. JOHNSTON

AMERICAN *URSI* BROADCASTS OF COSMIC DATA[1], APRIL TO JUNE, 1937, WITH AMERICAN MAGNETIC CHARACTER-FIGURE C_A, JUNE TO AUGUST, 1937

The data for terrestrial magnetism, sunspots, and solar constant are the same as given in previous tables.

The first three columns of the Table give (1) the magnetic character according to the scale 0-2 of the International Commission of Terrestrial Magnetism and Atmospheric Electricity, (2) the type featuring the day other than normal by the letters *b*, *p*, *o*, and *i* for days marked by bay, rapid pulsations, long-period oscillations, and irregular oscillations, respectively, and (3) the hour and minute of Greenwich mean time marking the beginning of a storm, the end of the storm being indicated in the footnote to the Table. The next two columns give the data relating to sunspots: (1) the number of groups of spots and (2) the total number of spots. It is to be noted that sunspot-numbers such as those from Zürich can be obtained from the number of groups and spots given in the Table by the formula $N=k\ (10g+s)$, where the mean value of k for Mount Wilson was 0.53 during 1936.

Mount Wilson Observatory is now supplying corrections and additions to the sunspot-data which are broadcast in the *URSI*gram. So far as possible, these additional and corrected values will be used in this tabular summary and will be designated as such in footnotes to the Table.

Beginning January 1, 1934, the magnetic information of the *URSI*-gram is for Cheltenham, Maryland, instead of Tucson, Arizona. In addition to this change in observatory, the data cover the 24 hours ending 8 A. M., 75° west meridian mean time, instead of the 24 hours ending at 7 A. M., 105° west meridian mean time.

[1]For previous announcements see Terr. Mag., **35**, 184-185 and 252-253 (1930); **36**, 54, 141, 258-259, and 358-360 (1931); **37**, 85-89, 189-192, 408-411, and 484-487 (1932); **38**, 60-63, 148-151, 262-265, 335-339 (1933); **39**, 73-77, 159-163, 244-247, 353-356 (1934); **40**, 111-115, 220-222, 334-336, 449-452 (1935); **41**, 85-87, 207-209, 315-317, 407-409 (1936); and **42**, 89-91, 207-209 (1937).

Summary American URSI Daily Broadcasts of cosmic data, April to June, 1937

Date	April						May						June					
	Magnetism				Sun-spot		Magnetism				Sun-spot		Magnetism				Sun-spot	
	Character	Type	G.M.T. Beginning Disturb.		Groups	Number	Character	Type	G.M.T. Beginning Disturb.		Groups	Number	Character	Type	G.M.T. Beginning Disturb.		Groups	Number
			h	*m*					*h*	*m*					*h*	*m*		
1	1	*i*	..	..	13	155	1	...	..	..	6	60	0	...	..	..	7	80
2	1	*i*	22	00	13	80	0	...	..	..	7	75	0	...	..	..	7	95
3	1	*i*	..	..	12	100	0	...	..	..	5	55	0	...	..	..	7	115
4	1	*i*	..	..	11	105	0	...	..	..	5	45	0	...	..	..	10	125
5	0	...	..	..	10	125	2	*i*	16	50	5	45	0	...	..	..	10	150
6	0	...	..	..	10	75	1	*i*	..	..	4	40	1	*i*	18	00	6	110
7	0	...	..	..	9	100	0	...	....	..	5	30	1	*i*	5	06	9	100
8	0	...	..	..	9	90	0	...	..	..	7	50	0	...	..	..	7	45
9	0	...	..	..	7	55	1	...	..	..	9	50	0	...	..	..	8	60
10	0	...	..	..	6	50	1	...	..	..	10	70	1	*i*	..	..	9	75
11	1	...	..	..	6	50	1	...	..	..	8	90	0	...	..	..	10	95
12	0	...	..	..	6	40	0	...	..	..	8	70	0	...	..	..	11	165
13	1	...	..	..	6	30	0	...	..	..	10	60	1	*i*	8	42	12	175
14	0	...	..	..	2	10	0	...	..	..	11*	60	0	...	..	..	14	200
15	0	...	..	..	5	40	1	...	..	..	11	90	0	...	..	..	9	130
16	0	...	..	..	5	35	1	...	..	..	13	105	0	...	..	..	12	245
17	0	...	..	..	7	65	0	...	..	..	10	130	1	...	..	..	11	155
18	1	*i*	17	40	10	85	0	...	..	..	10	145	0	...	..	..	13	215
19	0	...	..	..	11	105	0	...	..	..	13	115	0	..	..	..	13	125
20	1	...	..	..	10	75	0	...	..	..	15	200	0	...	..	..	12	130
21	1	...	..	..	9	120	0	...	..	..	12	200	1	*i*	17	50	11	125
22	0	...	..	..	7	100	0	...	..	..	...	...	0	...	..	..	14	95
23	0	...	..	..	7	120	0	...	..	..	12	200	1	*i*	13	00	12	90
24	1	*i*	12	00	9	165	0	...	..	..	11	175	0	...	..	..	12	70
25	2	*i*	..	..	11	215	1	*i*	19	00	...	...	1	...	..	..	8	105
26	2	*i*	15	48	9	195	1	...	..	..	9	65	0	...	..	..	9	120
27	2	*i*	17	40	8	190	0	...	..	..	8	110	0	...	..	..	7	95
28	2	*i*	18	50	8	125	1	*i*	18	40	6	85	1	*i*	..	..	9	85
29	2	*p*	24	00	7	95	1	*i*	..	..	7	55	0	...	..	..	7	120
30	1	...	..	..	7	80	1	*i*	..	..	6	70	0	...	..	..	7	100
31							0	...	..	..	7	65						
Mean	0.7	...	..	..	8	96	0.5	...	..	..	9	90	0.3	...	..	..	10	120

*Revision of value originally broadcast.

Greenwich mean time for ending of storms: 0^h, April 1; 10^h, April 4; 7^h, April 19; 9^h, April 25; 8^h, April 27; 5^h, April 28; 17^h, May 6; 2^h, June 7; 9^h, June 10; 15^h, June 14; 6^h, June 22; 24^h, June 23.

In accordance with information received from Dr. C. G. Abbot, Secretary of the Smithsonian Institution on March 6, 1937, solar-constant values were discontinued owing to important change in methods.

The data for the table of Kennelly-Heaviside Layer heights which is self-explanatory are supplied by the National Bureau of Standards.

As set forth in this JOURNAL for June, 1937, "The Department of

Kennelly-Heaviside Layer heights, Washington, D. C., April to June, 1937
(Nearest hour, Greenwich mean time, of all observations is 17)

Date	Freq.	Ht.	Date	Freq.	Ht.	Date	Freq.	Ht.	Date	Freq.	Ht.
1937	*kc/sec*	*km*	1937	*kc/sec*	*km*	1937	*kc/sec*	*km*	1937	*kc/sec*	*km*
Apr. 7	2,500	120	Apr. 27	5,100	680	May 26	4,200	220	June 16	5,000	250
" "	3,500	140	" "	5,200	640	" "	4,400	230	" "	5,400	320
" "	3,740	200	" "	5,300	650	" "	4,800	270	" "	5,600	520
" "	3,760	*	" "	5,400	760	" "	5,400	440	" "	6,000	490
" "	3,780	290	" "	5,500	*	" "	5,600	670	" "	6,800	500
" "	3,950	230	May 5	2,500	120	" "	5,800	470	" "	7,200	520
" "	4,400	250	" "	3,500	170	" "	6,200	630	" "	7,200	540
" "	5,000	270	" "	3,600	*	" "	6,600	550	" "	7,600	530
" "	5,400	300	" "	3,700	280	" "	7,000	480	" "	7,600	920
" "	6,200	300	" "	3,900	250	" "	7,400	560	" "	7,800	540
" "	9,400	350	" "	4,400	410	" "	7,600	*	" "	8,400	750
" "	9,400	400	" "	4,500	600	June 2	2,500	120	" "	8,600	*
" "	10,200	400	" "	4,600	*	" "	3,700	150	" 23	2,500	120
" "	10,200	550	" 14	2,500	120	" "	3,800	*	" "	4,000	130
" "	11,000	500	" "	4,000	120	" "	3,900	190	" "	4,150	140
" 14	2,500	120	" "	4,030	120	" "	4,200	130	" "	4,180	*
" "	3,600	140	" "	4,030	280	" "	4,300	230	" "	4,370	*
" "	3,650	150	" "	4,200	230	" "	4,400	230	" "	4,380	210
" "	3,650	260	" "	4,400	250	" "	4,800	250	" "	4,500	220
" "	4,000	210	" "	5,800	380	" "	5,000	360	" "	4,600	370
" "	4,400	270	" "	6,200	360	" "	5,100	*	" "	4,700	220
" "	5,400	300	" "	7,400	330	" "	5,200	400	" "	5,000	240
" "	6,200	300	" "	8,600	350	" "	5,800	350	" "	5,400	310
" "	9,400	330	" "	8,600	400	" "	6,600	380	" "	5,600	370
" "	9,400	370	" "	9,400	420	" "	6,600	460	" "	5,800	560
" "	10,800	490	" "	9,400	700	" "	7,200	420	" "	6,000	470
" "	11,000	*	" "	9,800	510	" "	7,200	600	" "	6,200	410
" 21	2,500	120	" "	10,000	*	" "	8,000	600	" "	7,000	440
" "	3,800	140	" 19	2,500	120	" "	8,200	*	" "	8,000	490
" "	3,900	*	" "	3,400	130	" 9	2,500	120	" "	8,000	560
" "	3,950	220	" "	4,000	140	" "	3,950	150	" "	8,800	660
" "	4,400	240	" "	4,100	*	" "	4,000	*	" "	9,000	*
" "	4,800	270	" "	4,330	230	" "	4,050	280	" 30	2,500	120
" "	5,200	320	" "	4,400	260	" "	4,200	230	" "	4,400	120
" "	6,200	320	" "	5,000	280	" "	4,400	240	" "	4,800	120
" "	7,000	340	" "	5,400	330	" "	5,000	370	" "	4,800	250
" "	7,800	370	" "	5,600	*	" "	5,200	700	" "	5,200	130
" "	8,800	380	" "	5,800	450	" "	5,400	520	" "	5,200	230
" "	8,800	570	" "	6,200	430	" "	5,600	500	" "	5,200	380
" "	9,400	460	" "	6,800	430	" "	6,000	580	" "	5,400	340
" "	9,600	*	" "	6,800	570	" "	6,200	540	" "	5,600	340
" 27	3,000	120	" "	7,000	440	" "	6,400	540	" "	6,200	350
" "	3,900	130	" "	7,000	640	" "	6,800	620	" "	7,000	360
" "	3,930	280	" "	7,800	700	" "	7,000	*	" "	7,000	390
" "	4,100	240	" "	8,000	*	" 16	2,500	120	" "	8,000	420
" "	4,400	270	" 26	2,500	120	" "	4,200	130	" "	8,000	540
" "	4,600	310	" "	3,500	130	" "	4,250	*	" "	8,800	520
" "	4,800	380	" "	3,900	*	" "	4,300	230	" "	9,000	*
" "	4,900	480	" "	3,980	320	" "	4,600	210			

* =No value obtained.

Terrestrial Magnetism and United States Coast and Geodetic Survey with the cooperation of the United States Army and United States Navy communication-services and several amateur radio stations have undertaken to supply an American character-figure based upon the reports of the seven American-operated observatories those of the Department of Terrestrial Magnetism at Huancayo in Peru and at Watheroo in Western Australia, and those of the United States Coast and Geodetic

American magnetic character-figure C_A for Greenwich half-days based on reports from Cheltenham, Honolulu, Huancayo, San Juan, Sitka, Tucson, and Watheroo for June to August, 1937

Day	June		July		August	
	0^h-12^h	12^h-24^h	0^h-12^h	12^h-24^h	0^h-12^h	12^h-24^h
1	0.4	0.1	0.2	0.4	0.1	0.2
2	0.0	0.1	0.0	0.2	1.4	0.7
3	0.0	0.1	0.2	0.0	0.4	0.6
4	0.1	0.4	0.1	0.1	1.0	0.4
5	0.4	0.9	0.6	0.6	0.1	0.1
6	1.1	0.8	0.5	0.8	0.0	0.3
7	0.1	0.5	0.6	0.3	0.4	0.2
8	0.0	0.4	0.1	0.1	0.0	0.2
9	0.0	0.1	0.1	0.7	0.1	0.1
10	0.7	0.2	0.6	0.1	0.0	0.2
11	0.1	0.0	0.1	0.9	0.1	0.3
12	0.0	0.0	0.3	0.1	0.1	0.1
13	0.6	0.7	0.0	0.4	0.1	0.1
14	0.3	0.3	0.8	1.0	0.1	0.2
15	0.3	0.4	0.4	0.6	0.5	0.1
16	0.4	0.4	0.0	0.2	0.0	0.0
17	0.4	0.5	0.2	0.4	0.0	0.1
18	0.3	0.1	0.0	0.3	0.1	0.1
19	0.1	0.1	0.1	1.1	0.1	0.1
20	0.8	0.7	0.8	0.6	0.0	0.2
21	0.4	0.2	0.5	0.4	0.1	0.1
22	0.2	0.8	1.1	0.9	1.7	1.1
23	0.1	0.2	0.5	0.6	0.4	0.1
24	0.2	0.6	1.1	0.6	0.1	0.1
25	0.2	0.1	0.6	0.5	0.0	0.1
26	0.0	0.1	0.4	0.2	0.1	0.3
27	0.6	1.0	0.0	0.1	0.3	0.6
28	0.6	0.6	0.0	0.0	0.2	0.4
29	0.2	0.1	0.0	0.1	0.3	0.0
30	0.1	0.1	0.1	0.2	0.0	0.0
31			0.1	0.1	0.1	0.1
Means	0.3	0.4	0.3	0.4	0.3	0.2
	0.3		0.4		0.2	

Survey at Cheltenham (Maryland), Honolulu (Hawaii), San Juan (Puerto Rico), Sitka (Alaska), and Tucson (Arizona)." This character-figure is being designated C_A, and the values for June to August, 1937, are given in the accompanying Table.

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C.

C. C. Ennis

AVERAGES OF CRITICAL FREQUENCIES AND VIRTUAL HEIGHTS OF THE IONOSPHERE, OBSERVED BY THE NATIONAL BUREAU OF STANDARDS, WASHINGTON, D. C., MAY TO AUGUST, 1937[1]

The following ionosphere data are in continuation of those published for 1934-36 in this Journal.[2] The symbols used are:

[1]Communicated by the director of the National Bureau of Standards of the United States Department of Commerce.
[2]T. R. Gilliland, S. S. Kirby, N. Smith, and S. E. Reymer, Terr. Mag., **41**, 379-388 (1936).

TABLE 1—*Ionosphere data, National Bureau of Standards, Washington, D. C.*

EST	h_E	h_{F_1}	h_{F_2}	f_E	$f^\circ_{F_1}$	$f^x_{F_2}$	h_E	h_{F_1}	h_{F_2}	f_E	$f^\circ_{F_1}$	$f^x_{F_2}$
			May, 1937						*June, 1937*			
00			321			6920			304			713
01			316			6700			302			670
02			318			6420			312			624
03			322			6000			323			584
04			319	1000#		5690			325	1080#		539
05			293	1760		5930		280*	306	1930#		565
06	...	254	317#	2520	3216#	6400	126*	250	323#	2650	4000	665
07	121	243	368#	2938	4250#	6950#	122	245	342#	3145	4405	726
08	119	237	398#	3292	4750#	6800#	119	231	358#	3500	4730	796
09	117	233	446#	3484	4960#	7050#	117	231	356#	3770	5060	830
10	117	224	452#	3736	5060#	7310#	119	228	368#	3990	5420#	846
11	119	220	458#	3917	5190#	7510#	119	227	382#	4125	5520#	840
12	118	226	480#	3940	5270#	7720#	119	227	392#	4197	5510#	844
13	119	229	483#	3910	5240#	7840#	119	226	402#	4152	5510#	850
14	120	242	450#	3784	5210#	7990#	119	232	398#	4000	5520#	862
15	121	245	426#	3597	5050#	8010#	118	235	378#	3888	5320#	878
16	119	242	395#	3393	4800#	8100#	120	240	354#	3634	5070#	888
17	123	247	352#	3003	4280	8010#	123	246	330#	3264	4570	892
18		258	300	2500	3650*	8100#	124	257	308#	2777	3960*	906
19			272	1750*		8100#			275	2090#		902
20			270			7980#			271	1280#		890
21			283			7570#			287			854
22			301			7180#			295			808
23			318			7040			299			760
			July, 1937						*August, 1937*			
00			301			7130			310			725
01			307			6760			316			700
02			308			6300			307			657
03			315			5925			313			628
04			274	1250#		5460	...		319	830#		599
05			308	1900#		5530	...		304	1250#		579
06	120*	257	364	2560	3608*	6090#	125	260	276	2472		667
07	120	242	390#	3150	4355*	6900#	124	245	336#	2950	5200[a]	755
08	117	233	420#	3463	4925#	7300#	120	231	360#	3358	5600	830
09	118	240	440#	3800	5150#	7625#	118	230	360#	3691	5800	873
10	116	226	453#	3934	5290#	7720#	119	220	358#	3970	5950	900
11	118	222*	475#	4081*	5325#	7800#	118	217*	393#	4093	6100	915
12	118	225*	494#	4172*	5350#	7740#	118	228	400#	4167	6200	903
13	119	234*	483#	4162*	5350#	7720#	118	228	389#	4134	6300	895
14	119	238*	489#	3991*	5350#	7720#	119	229	389#	3946	6300	903
15	121	241*	485#	3885*	5300#	7640#	120	235	375#	3761	6200	900
16	120	243	450#	3730	5200#	7915#	120	237	353#	3527	6100	903
17	121	249	380#	3330	4900#	7915#	123	241	340#	3108	5700	897
18	122	253	310#	2816#	4075*	7980#	...	257	295#	2637		900
19	...	274	286	2000#	3075*	8080#	...		274	1950#		903
20			272	1400#		8200#	...		278	1300#		875
21			287			8220#			287			833
22			305			7714			294			788
23			295			7420			298			756

[a] f_{F_1} observations for August 4 only. f_{F_1} not well defined except on days of ionosphere storms.

h_E = E-region virtual height, kilometers (lowest measured height)
h_{F_1} = F_1-region virtual height, kilometers (lowest measured height)
h_{F_2} = F_2-region virtual height, kilometers (lowest measured height)
f_E = E-region critical frequency, kilocycles per second, ordinary ray
$f^o_{F_1}$ = F_1-region critical frequency, kilocycles per second, ordinary ray
$f^x_{F_2}$ = F_2-region critical frequency, kilocycles per second, extraordinary ray
EST = Eastern standard time (75° west meridian time); add 5 hours for Greenwich time
= Manual measurements
* = Less than ten measurements with automatic recorder.

NATIONAL BUREAU OF STANDARDS,
UNITED STATES DEPARTMENT OF COMMERCE,
Washington, D. C.

AURORAL OBSERVATIONS ON AUGUST 1, 1937, AT MALCOLM ISLAND, CANADA

An interesting report of an auroral observation made at Pultney Point, Malcolm Island, near Vancouver Island, Canada, on August 1, 1937, has been received from Dr. T. G. Thompson of the Oceanographic Laboratories, University of Washington. The report states:

"About $23^h\ 30^m$ (probably 120° west meridian time) we noted a great beam of greenish light to the southeast. The beam shifted and moved from southeast toward the west and eventually took the form of an enormous shaft of light extending across the sky. It was considerably above the clouds and we got a very beautiful cloud-effect. The light was reflected in the waters of Johnstone Strait much the same as moonlight.

"After watching it for about half an hour, the light bent at right-angles to the westward, running horizontally for a considerable distance, parallel to the horizon, and then bent at right-angles again toward the Earth. We had seen several displays of northern lights at the time, but as this light seemed to originate at the east of south it apparently did not have any connection with the aurora. The same phenomenon was witnessed by residents in the San Juan Islands, some 200 miles to the south of our point of observation."

The phenomenon mentioned in this report was undoubtedly an auroral display. Commenting on the observation, Dr. J. Bartels pointed out that the point of observation lies in about 50°.5 north latitude in 127° east longitude, making the geomagnetic latitude about 60°.8 north—nearly 7° south of the zone of maximum auroral frequency. The display was seen during a comparatively intense magnetic storm.

This magnetic storm began at $21^h\ 49^m$ GMT, August 1. It was marked by large bays in all three elements at the Cheltenham Observatory from 5^h to 9^h on August 2. A sharp decrease in vertical intensity bringing that element to a minimum over 200 gammas below its pre-storm value at about $6^h\ 30^m$ on August 2 was the most outstanding feature of the disturbance. Magnetic disturbances of this sort are rather uncommon at Cheltenham but occur quite frequently at places close to the auroral

zone. The appearance of one of these disturbances at a station in middle latitudes indicates a temporary southward shift of the auroral zone, permitting observation of the polar aurora in comparatively low latitudes. Observation of an aurora in the southern sky from a place already several degrees south of the zone of maximum auroral frequency together with the appearance of a typical auroral-zone magnetic disturbance at a middle-latitude station strongly indicates that at this particular time the auroral zone was displaced considerably to the southward.

It is interesting to note that a radio fade-out accompanying a bright chromospheric eruption occurred at 16^{h} 15^{m} GMT on the day preceding the storm, July 31 (see article in this issue of the Journal by L. V. Berkner and H. W. Wells). The two effects—auroral-magnetic and radio fade-out—probably have no direct connection. However, those active sunspot-regions in which chromospheric eruptions most frequently appear also seem to be regions which give rise to terrestrial-magnetic storms. It should be pointed out that the effects caused by bright chromospheric eruptions radio fade-out and sometimes magnetic—are manifested only on the daylight side of the Earth, most strongly near the sub-solar point, while the polar auroras, as the name implies, are high-latitude phenomena and tend to occur near the midnight meridian. It must not be overlooked that the activity which gives rise to the ultraviolet radiation from a sunspot-region which produces radio fade-outs and the special type of magnetic disturbance sometimes accompanying them may also produce another type of radiation which travels more slowly toward the Earth and gives rise to auroras and magnetic storms.

Department of Terrestrial Magnetism, A. G. McNish
Carnegie Institution of Washington,
Washington, D. C., August 17, 1937

PRINCIPAL MAGNETIC STORMS

Sitka Magnetic Observatory
April to June, 1937[1]

(*Latitude* 57° 03′.0 *N., longitude* 135° 20′.1 *or* $9^h\ 01^m.3$ *W. of Gr.*)

April 24-25—A slight disturbance beginning abruptly at $12^h\ 02^m$ GMT, April 24, marked the beginning of several days of severe storms. This disturbance continued with increasing activity until it had reached its maximum intensity at $00^h\ 10^m$, April 25. After about two hours the disturbance stopped quite sharply and in another five hours the three elements were normal. Ranges were: *D*, 69′; *H*, 545 gammas; *Z*, 298 gammas.

April 25-26—After seven or eight hours of calm following the above disturbance, a severe storm began at $15^h\ 48^m$ GMT, April 25. It was marked by a sudden commencement in all three elements and gradual shortening of the period of oscillation of the magnets and increasing the amplitude until the period of the vibrations was as low as three minutes and the amplitudes were 375 gammas in *H*, 120 gammas in *Z*, 55′ in *D*. These unusually rapid vibrations were particularly marked from 19^h GMT, April 25, until 05^h, April 26. The storm was at its height between 20^h and 23^h, April 25. From 07^h, April 26, the trace was only moderately disturbed. Ranges were: *D*, 114′; *H*, 418 gammas; *Z*, 187 gammas.

April 26-27—At $17^h\ 55^m$ GMT, April 26, with an abrupt commencement the storm gradually increased in intensity, and at 19^h the fluctuations were very rapid. A notable feature of this period of activity was a sudden increase of 800 gammas in *H* and 500 gammas in *Z* between $22^h\ 49^m$ and $23^h\ 00^m$. Thereafter the storm gradually diminished and at 07^h, April 27, had returned to normal. Ranges were: *D*, 96′; *H*, 1422 gammas (*H*-maximum off sheet, range estimated); *Z*, 602 gammas.

April 27-28—At about 19^h GMT, April 27, and slowly increasing in intensity the most severe storm of this group, and of the past several years, began. By 04^h, April 28, the three elements were fluctuating rapidly and with very large excursions, at times during this interval *D* varied as much as 2°, *H* varied from 400 to 500 gammas, and *Z* varied 500 to 600 gammas in three to ten minutes. This violent activity ceased about $14^h\ 30^m$, April 28. The storm gradually diminished in intensity and stopped about 24^h, April 28. The three elements remained moderately disturbed for several days. Ranges were: *D*, 193′, *H*, 2090 gammas (*H*-maximum off sheet, range estimated); *Z*, 1384 gammas.

May 4-5—A moderate storm began gradually at 20^h GMT, May 4, and increased slowly to maximum intensity between $04^h\ 30^m$ and $07^h\ 30^m$, May 5. For about two hours the elements remained only moderately disturbed, then there was a sudden decrease of all three elements at $09^h\ 44^m$, May 5—*H* decreasing 465 gammas, *Z* decreasing 300 gammas, and east declination decreasing 18′. This sudden activity continued for about three hours, and then the elements gradually returned to

[1]Communicated by R. S. Patton, Director, United States Coast and Geodetic Survey.

normal at $17^h\ 30^m$, May 5. Ranges were: *D*, 224′; *H*, 1490 gammas; *Z*, 1020 gammas.

May 28-29—A small disturbance began abruptly at $01^h\ 54^m$ GMT, May 28, and increased gradually for about ten hours, then subsided slowly during the next 18 hours. The elements showed characteristic bays with superimposed short-period vibrations. Rapid vibrations were noted particularly in the declination. The disturbance ceased at $10^h\ 30^m$, May 29. The ranges were: *D*, 75′; *H*, 880 gammas; *Z*, 620 gammas.

June 5-6—A small disturbance began abruptly at $11^h\ 52^m$ GMT, June 5, and then remained relatively quiet until 21^h when it gradually increased in intensity until $07^h\ 08^m$, June 6, when a sudden decrease of 770 gammas in *H*, of 465 gammas in *Z*, and an increase of 37′ in east declination precipitated a period of activity lasting for about nine hours. The disturbance ceased suddenly at $17^h\ 50^m$, June 6. The ranges were: *D*, 140′; *H*, 1081 gammas; *Z*, 760 gammas.

ROBERT E. GEBHARDT, *Observer-in-Charge*

CHELTENHAM MAGNETIC OBSERVATORY
APRIL TO JUNE, 1937[1]

(*Latitude* 38° 44′.0 *N., longitude* 76° 50′.5 *or* $5^h\ 07^m.4$ *W. of Gr.*)

April 24-28—A magnetic storm of great severity was in progress from noon of April 24 to midnight of April 28. The storm was not continuously severe during the full period but had the appearance of four storms with lulls between them. The range of declination for the whole storm was 72′; of vertical intensity 866 gammas; and the estimated range of horizontal intensity was 735 gammas. The storm began with moderate activity but at 19^h GMT, April 24, it increased in violence and was very active until 02^h, April 25, when it moderated. This period of the storm was characterized by a very high value of vertical intensity at $23^h\ 45^m$ when it reached a value about 425 gammas above normal. The ranges for the period were: *D*, 36′; *H*, 223 gammas; and *Z*, 485 gammas. After a time of comparative quiet the storm was again active from $15^h\ 48^m$, April 25, to 7^h, April 26. Between 19^h and 23^h, April 25, all three elements were very active with short-period perturbations of moderate ranges in *D* and *Z* but large range in *H*. This part of the storm was characterized by high values and great range in *H*. The *H*-trace went completely off the magnetogram, indicating a range of more than 400 gammas. The ranges in *D* and *Z* during this time were 36′ and 106 gammas respectively. The elements were again fairly quiet until $17^h\ 40^m$, April 26, when the storm once more became violent for a period of 11 hours. This period was notable for the high values in both *H* and *Z*; the *H*-trace again left the magnetogram. The ranges were: *D*, 48′; *H*, more than 400 gammas; and *Z*, 382 gammas. Another period of quiet occurred until $18^h\ 40^m$, April 27. Then the storm again became violent and was characterized by low values of *H* and *Z* and a large range in *D*. The ranges were: *D*, 72′; *H*, 455 gammas; and *Z*, 523 gammas. The storm ended at midnight, April 28.

May 4-5—A disturbance began at $16^h\ 11^m$ GMT, May 4, and ended at 18^h, May 5. The most notable feature was a peak in all three elements

[1]Communicated by R. S. Patton, Director, United States Coast and Geodetic Survey.

between 6^h and 7^h, May 5, when H and Z decreased and west D increased. The ranges were: D, 38′; H, 270 gammas; and Z, 236 gammas.

May 27-29—A disturbance of moderate intensity began at $12^h\ 25^m$ GMT, May 27, and continued until 12^h, May 29. The oscillations were irregular. High values of Z occurred during the 22nd hour on both days, May 27 and 28. The ranges were: D, 32′; H, 184 gammas; and Z, 165 gammas.

June 5-7—A disturbance began at 18^h GMT, June 5, and ended at 02^h, June 7. The perturbations were of moderate intensity. The ranges were: D, 24′; H, 187 gammas; and Z, 175 gammas.

ALBERT K. LUDY, *Observer-in-Charge*

TUCSON MAGNETIC OBSERVATORY APRIL TO JUNE, 1937[1]

(*Latitude* 32° 14′.8 *N., longitude* 110° 50′.1 *or* $7^h\ 23^m.3$ *W. of Gr.*)

April 2-3—A disturbance began at $05^h\ 02^m$ GMT, April 2, the chief movement being an increase of 13 gammas in H. This was followed by several long, shallow bays, and at 12^h the disturbance seemed to have ended. But at 16^h there were a few shorter-period oscillations in H and D, of small amplitude. These were followed by a marked depression in the average value of H, which lasted until about 07^h, April 4. During this period the traces were relatively quiet except for a few bays between 02^h and 07^h, April 3.

April 12-13 A mild disturbance began at $08^h\ 53^m$ GMT, April 12, marked chiefly by an increase in H of 26 gammas, although the other elements were very slightly disturbed. H continued high until 16^h, when it began gradually to decrease, reaching a minimum about 21^h. Then it slowly increased again and, after a bay between 00^h and 02^h, April 13, the disturbance was over.

April 24-28 –A sharp increase in H of 38 gammas at $12^h\ 00^m$ GMT, April 24, marked the beginning of one of the most severely disturbed periods on record at this station. After the beginning, H remained high for some hours, but there was only moderate activity until 19^h, when H began to decrease, executing several large bays and smaller fluctuations in the process, and reaching a minimum at $01^h\ 09^m$, April 25. Thereafter H increased again and the oscillations died out, so that the storm appeared to be over by 09^h, except that H was still far below normal. During this period D was moderately disturbed. But at $15^h\ 47^m$, there was a new beginning, sharper than the first one, though with a smaller initial movement. For the next 15 hours the oscillations of H were sharp and violent, D and Z also being decidedly disturbed. H reached its maximum value for the storm at $19^h\ 33^m$. From 07^h to $17^h\ 55^m$, April 26, was another period of relative calm. At the latter moment there was a third beginning, sharper than either of the other two, and affecting both H and D. This time the short-period oscillations were of smaller amplitudes, and the large movements more pronounced in all the elements. After another lull from 07^h, April 27, to 19^h, the long-period activity was gradually renewed, reaching its maximum intensity about 05^h, April 28, and continuing undiminished until 12^h. During this

[1]Communicated by R. S. Patton, Director, United States Coast and Geodetic Survey.

period D fluctuated through a range of about 28′. From 12^h to 24^h there was only moderate long-period activity, but more of the short-period oscillations again. At 24^h, April 28, the storm proper ended, though for some days afterward H remained well below normal and was somewhat disturbed. The complete range of H during the storm was a little more than 300 gammas.

May 4-5—This storm began gradually about 17^h GMT, May 4. For about 13 hours the chief activity consisted of a gradual decrease in H, accompanied by minor oscillations in H and D. The range of H in this period was about 155 gammas. At about 06^h, May 5, deep bays occurred in H and D, after which the activity gradually decreased, the storm ending at about 16^h.

May 25-30—This could hardly be called a storm, but the entire period was somewhat disturbed. There were no large changes in any of the elements, the activity consisting mostly of slow, long-period movements, chiefly in H and D.

June 4-6—A very moderate beginning at 14^h 20^m GMT, June 4, was followed by relative calm until about 24 hours later. Then H decreased slowly, and at first smoothly. At about 19^h small long-period oscillations began, with gradually increasing amplitudes. After a moderately deep bay at 07^h, June 6, the oscillations gradually died out. H remained somewhat low until 24^h, when the storm was over.

John Hershberger, *Observer-in-Charge*

Huancayo Magnetic Observatory
May to June, 1937

(Latitude 12° 02′.7 *S., longitude* 75° 20′.4 *or* 5^h 01^m.4 *W. of Gr.)*

May conditions—The average character-number for May was low, namely 0.1. Only three days during the month were classed as other than zero-days. These were May 4, 5, and 28. May 5 was very disturbed. Two sudden commencements occurred during the month.

May 3—A sudden commencement was noted at 16^h 06^m GMT, May 3. D and Z increased slightly. A sharp decrease of 3 gammas in H was followed by an increase of 50 gammas in an interval of five minutes. The H-trace was moderately disturbed for two hours following the sudden commencement.

May 4-5—A sudden commencement occurred at 16^h 56^m GMT, May 4, which showed strong similarities with that of the previous day. D and Z increased slightly. H decreased 1 gamma and increased 60 gammas in an interval of five minutes. H was very disturbed during the two hours following the commencement. From 01^h to 20^h, May 5, the H-trace, besides being very low in value, was also much disturbed. Two marked features of this disturbed period were (a) a large bay (minimum) in H between 01^h and 06^h and (b) a rapid increase in H culminating at 15^h 05^m, followed by a sharp decrease to a minimum at 15^h 45^m. During this interval H decreased 240 gammas. The spectrohelioscopic record listed small bright flocculi on the Sun, May 3 and 5. On May 4 the sky was overcast. At 16^h 51^m, May 25, a very sharp peak in H occurred which was coincident with a sudden solar disturbance.

June conditions—The average character-number for June was low,

namely 0.1. Only three days during the month were classed as other than zero-days. These were June 6, 13, and 27. June 5 showed a low value of H. Three sudden commencements were recorded. The spectroheliοscopic record listed solar activity on June 5, 13, and 27. A very bright and active solar flocculus was seen on June 14 but no marked magnetic activity was noted at the time.

June 10—A sudden commencement occurred at $05^h\ 07^m$ GMT, June 10. There was a small effect in D, an increase in Z of 10 gammas in three minutes, and an increase in H of 60 gammas in the same interval. The traces were relatively quiet afterwards.

June 13—A sudden commencement was recorded at $08^h\ 43^m$ GMT, June 13. The effect in D was slight. An increase of 6 gammas occurred in Z in three minutes and an increase in H of 25 gammas in the same interval. This was followed by fairly large oscillations in H until 18^h.

June 22—A sudden commencement was recorded in Z and H at $09^h\ 57^m$ GMT, June 22. Z increased 5 gammas and H increased 17 gammas in three minutes. The traces were only slightly disturbed afterwards.

June 27—Between 12^h and 19^h GMT, June 27, a large number of oscillations occurred in all three elements. Sharp peaks in the traces began at $15^h\ 20^m$, reached maxima at $15^h\ 26^m$, and returned to normal values by $15^h\ 32^m$. The ranges during this interval were as follows: D, 4′; Z, 14 gammas; H, 220 gammas. The peaks in all three elements represented increases in value.

FRANK T. DAVIES, *Observer-in-Charge*

APIA OBSERVATORY
APRIL TO JUNE, 1937

(*Latitude* 13° 48′.4 *S., longitude* 171° 46′.5 *or* $11^h\ 27^m.1$ *W. of Gr.*)

April 12—A disturbance commenced suddenly at $08^h\ 50^m$ GMT, April 12, with an instantaneous increase in H equal to 12 gammas. The maximum value of H was attained between 11^h and 12^h and the minimum at $18^h\ 25^m$. The range in H was 46 gammas.

April 24-25—Disturbance commenced at $12^h\ 00^m$ GMT, April 24, with a sudden increase in H equal to 17 gammas and oscillations in the record of D within a range of a few minutes of arc. The values of H fell to a minimum at $01^h\ 12^m$, April 25, and the range of variation in H was 120 gammas.

April 26-30—An intense disturbance began abruptly at $17^h\ 53^m$ GMT, April 26, with an increase of 32 gammas in H and oscillations in the record of D having a range of 2′. The maximum value of H occurred at $18^h\ 48^m$ and a minimum occurred next day at $02^h\ 08^m$, the range during the initial stages of the storm being 240 gammas in H. The storm continued on April 28 with great fluctuations in H but had subsided again by April 30.

May 4-5—A sudden commencement occurred at $16^h\ 53^m$ GMT, May 4, with increases of 6 gammas in H and one gamma in Z. The maximum was at $18^h\ 22^m$, May 4, the minimum at $06^h\ 05^m$, May 5, and the range was 186 gammas in H.

June 10—A slight disturbance extending over a range of 47 gammas in H between a maximum at $05^h\ 43^m$ GMT, June 10, and a minimum at

$09^h\ 00^m$ began at $05^h\ 03^m$ with abrupt increases of 24 gammas in H and 7 gammas in Z.

June 13—H increased abruptly by 13 gammas at $08^h\ 39^m$ GMT, June 13, and reached a maximum at this time, afterwards falling to a minimum at $11^h\ 53^m$ through a range of 77 gammas. The change recorded in Z was less than one gamma.

J. Wadsworth, *Director*

Watheroo Magnetic Observatory
May to June, 1937

(*Latitude* 30° 19′.1 *S.*, *longitude* 115° 52′.6 *or* $7^h\ 43^m.5$ *E. of Gr.*)

May 28—There was a sudden commencement at $01^h\ 51^m\ 50^s$ GMT, May 28, as shown by the record of the Crichton-Mitchell vertical-intensity inductometer. D suddenly moved 1′ westerly, then 3′ easterly in about forty seconds, followed by a movement 5′ westerly in two minutes. H suddenly increased 5 gammas, then decreased 17 gammas in about forty seconds; these movements were followed by an increase of 18 gammas in two minutes. The numerical value of Z suddenly increased 4 gammas then decreased 13 gammas in about forty seconds; then followed an increase of 20 gammas in three minutes. The character of the trace was "1" during the next twenty-four hours.

June 10—There was a sudden commencement at $05^h\ 05^m\ 10^s$ GMT, June 10. D moved 1′.6 westerly abruptly, then 5′ easterly during the next five minutes of time. H increased 9 gammas abruptly; during the next six minutes of time, there was a slight pause and a further increase of 32 gammas. The numerical value of Z increased 4 gammas and then decreased 32 gammas in five minutes. All the elements returned to normal activity after three hours had elapsed.

J. W. Green, *Observer-in-Charge*

REVIEWS AND ABSTRACTS

D. La Cour. *Transactions of the Edinburgh meeting, September 17-24, 1936.* Edited by D. la Cour in collaboration with J. Bartels and M. Bruun de Neergaard. Bulletin No. 10,. Association of Terrestrial Magnetism and Electricity, International Union of Geodesy and Geophysics. Copenhagen, Hörsholm Bogtrykkeri, Hösholm, 1937 (x+458 with illus.). 24 cm.

The present volume contains the transactions of the Edinburgh meeting of the Association of Terrestrial Magnetism and Electricity, one of the seven associations which constitute the International Union of Geodesy and Geophysics. This meeting was the sixth thus far held, the previous ones having taken place in Rome (1922), Madrid (1924), Prague (1927), Stockholm (1930), and Lisbon (1933). The next meeting, in accordance with an action taken at Edinburgh, will be held in Washington, D. C., in 1939.

The form of the *Transactions* of the previous meeting (Lisbon, 1933) has been closely followed even to the style of type and quality of paper, both of which are excellent. In these *Transactions*, however, the English language has been substituted for French in the title and editorial remarks. The reviewer regrets to note again the omission of the general list of addresses of members of the Association such as appeared in the volumes for the Prague and Stockholm meetings and which could have been added with little additional labor and expense thus making available a useful up-to-date refference-list.

The volume is divided into seven parts, the first of which contains the agenda of the meetings, list of those present, minutes of the meetings, address of the President, reports of the Secretary and Auditing Committee, and summary of the minutes of the Executive Committee. It contains, as frontispiece, a portrait of the late Sir Arthur Schuster, and on page 25, a plate showing the group which took part in the excursion to Eskdalemuir Observatory, September 23, 1936. In opening his address the President enumerated the losses by death since the Lisbon Meeting of eminent investigators in the sphere of activity represented by the Association, mentioning particularly the Association's Senior Vice-President, Prof. V. Carlheim-Gyllensköld. He drew attention to the spirit of cooperation and harmonious relations existing between the Commission of Terrestrial Magnetism and Atmospheric Electricity of the International Meteorological Organization and the Association and the constantly increasing amount of data resulting from the Polar Year being made available at the Central Bureau of the International Polar Year Commission. He emphasized the importance of the decision of the British Admiralty to construct a non-magnetic vessel for resuming the magnetic and electric survey at sea so tragically interrupted by the loss of the *Carnegie* in 1929. He then called attention to certain matters on the agenda; Ways and means of achieving more economical and effective continuation of compilations, reductions, discussions, and publication of results obtained; instrumental methods and technique; character of publication of data and their distribution; more effective methods of publication to insure greater use by investigators than is possible by those now in use; adequate and frequent intercomparisóns of instruments; variations of electrical conditions of the ionosphere as an aid to the study of cosmical correlations of the Earth's magnetic and electric fields; problems of earth-currents and atmospheric electricity awaiting solution; definition and adoption of symbols pertaining to geomagnetic coordinates, magnetic coordinates, and geomagnetic time. He indicated the distinct step forward in the unification of researches in Earth physics through the appointment of a commission for the study of the Earth's crust. In brief, the address contained a summary of the outstanding advances in geophysics during the last three years, and an indication of the urgent problems awaiting solution at the present time.

Part II contains the French and English versions of the statutes of the Association as adopted at the session of September 18, 1936.

Part III is devoted to a presentation of the National Reports received from 14 countries, including the belated report from the Greek National Committee received too late for inclusion in the Transactions but distributed with them. In the case of several countries more than one report was received so that the total number presented amount to 28. A perusal of these reports leaves the impression that, despite economic difficulties,

good progress in terrestrial magnetism and electricity has been made throughout the world during the past three years.

In Part IV are included the 17 reports on special topics by committees and reporters appointed at Lisbon together with the reports of committees appointed by the Commission of Terrestrial Magnetism and Atmospheric Electricty of the International Meteorological Organization at its meeting in Warsaw in September 1935. Of special interest are the reports of the Committee to Consider Existing and Desirable Distribution of Magnetic and Electric Observatories and the better coordination of work and publications of existing observatories and the special Committee on Magnetic Secular-Variation. Both of these reports are truly international in scope; the former presents an excellent summary of the present status of observatory-work arranged by countries with appropriate comments, and the latter is a statement of what has been accomplished during July 1, 1933, to June 30, 1936, toward meeting the suggested minimum needs for secular-variation studies published in the *Transactions* of the Lisbon meeting. Other reports deal with the publication of the numerical magnetic character of days, sudden commencements of magnetic storms, auroras, numerical character-figures, relations between solar activity and terrestrial magnetism, international collaboration to advance the study of the Moon's effect upon geophysical phenomena, and errors arising in ion-count work. There are in all six reports resulting from action taken at the Warsaw Meeting of the Commission of Terrestrial Magnetism and Atmospheric Electricity. They pertain to the publication of magnetic character during the Polar Year 1932-33, instrumental comparisons by means of apparatus circulated by mail, codes to describe adequately magnetic disturbances and perturbations, convention regarding the sense of earth-current components, magnetic classification of Greenwich days prior to 1906, and uniformity of magnetic charts.

The communications on various subjects, 41 in number, presented at the meeting are reproduced in Part V. They are classified under the headings: (*A*) Terrestrial magnetism; (*B*) ionosphere and cosmic radiation; (*C*) atmospheric and terrestrial electricity; and (*D*) miscellaneous. Several of these communications are in reality reports dealing with progress in current investigations.

In Part VI are contained the proposals on various subjects, namely, a thesaurus of magnetic values, circulation of QHM for world-wide intercomparison of the measurements of the magnetic force and control of variometers for declination and horizontal intensity, atmospheric electricity and static, classification of terrestrial magnetism according to subjects, disturbed days 1906-14, establishment in Iceland of temporary stations for quick-run magnetic registration, methods of investigating relationships between aurora and changes in the Earth's magnetic field, and methods of measuring auroral photographs.

The concluding section (Part VII) contains the resolutions adopted at the meeting (see Terr. Mag., **41**, 360-362, 1936), the composition of the Executive Committee and of the 12 other committees and reporters continued or appointed at Edinburgh.

An examination of this volume of 458 pages leaves no doubt as to the sustained interest in geophysical subjects in all parts of the world. It is, in fact, an epitome of three years' activity and hence of much practical value to all students of terrestrial magnetism and electricity. Aside from the intrinsic value of the contents, the reviewer cannot fail to emphasize the excellent manner in which the volume has been edited and produced. It is a publication worthy of the science it represents and highly creditable to those who have contributed to its pages as well as to those who have had a part in its publication.

H. D. Harradon

British National Committee for the Polar Year: *British Polar Year Expedition, Fort Rae, N. W. Canada 1932-33.* Volume I, Discussion of results, meteorology, terrestrial magnetism and aurora, atmospheric electricity. Volume II, Tables, meteorology, terrestrial magnetism, atmospheric electricity. London, 1937 (xv+336; xii+228). 32 cm.

The site of the main station (latitude 62° 49′.8 north, longitude 116° 04′.1 west) where the comprehensive program of work was carried out by the British Polar Year Expedition at Fort Rae, Northwestern Canada, during the Second International Polar Year 1932-33, was approximately 15 miles northwest of Old Fort Rae where the Expedition of 1882-83 was located and which was occupied intermittently through the year 1932-33 as a substation for auroral photography and magnetic observations. The publication under review consists of the first two volumes of results of the 1932-33 Expedition.

The work opens with a short narrative of the Expedition by its leader, Dr. J. M.

Stagg, giving many facts helpful to an understanding of the results and affording an insight into the difficulties encountered by the Expedition.

The first section consisting of over 100 pages of Volume I and 159 tables of Volume II is devoted to the presentation of the meteorological data, including descriptions of instruments and methods together with extensive tabulations and analyses of the vast body of material pertaining to the various meteorological elements.

The second section, by the leader of the Expedition, contains a discussion of the terrestrial-magnetic and visual auroral results and occupies 181 pages of text and 111 tables. Continuous registration of horizontal force, vertical force, and declination were obtained by three complete sets of magnetographs two of the standard and one of the quick-running type. Azimuth, scale-value, and base-line determinations are discussed in detail. Consideration is given to the effect of temperature- and humidity-changes on the instruments as reflected in the results. Observations made at the 1882-83 location, permit, through comparison with the older values, drawing some conclusions regarding the secular change. Daily and seasonal variations are analyzed and much attention is given to features of the corresponding current-systems for both quiet and disturbed days. The results of harmonic analyses of the diurnal curves and vector-diagrams depicting the results under different conditions and groupings of the data are also presented.

An ambitious program of visual and photographic records of auroral displays was carried out. The present report on this subject deals largely with the statistical aspects as determined from assigned intensity-figures. Some representative auroral characteristics are described. Results of a preliminary study of the correlation between auroral and magnetic activities from statistical and individual comparisons are given but results of further investigation of this subject, as well as those to be obtained from measurements of 900 pairs of auroral photographs, are reserved for a later volume.

The presentation of the atmospheric-electric results concludes the report. This part of the program embraced the continuous registration of the potential of the air with a Benndorf electrograph and morning and afternoon determinations of the number of positive and negative small ions, of positive conductivity by the Wilson method, and of the number of Aitken nuclei. The factor for reducing the air-potentials to volts per meter was adequately determined. Hourly values of potential-gradient and individual observations of the other elements are tabulated. The rate of production of small ions in a zinc container was measured on a number of occasions and several 24-hour series of measurements of this factor, as well as of conductivity and small-ion number, were made with eye-reading instruments. Harmonic analyses of the diurnal variation in potential-gradient yielded a 24-hour component in good agreement with the established universal wave. The author's analysis of the gradients accompanying drift-snow is especially interesting. The most surprising result in this section, however, is that of the annual variation in the potential-gradient which has its minimum in winter and a maximum in summer. The author explains this anomaly as well as most of the other variations in the electrical elements as the effect of mixing in the atmosphere as indicated by varying wind-velocities.

The British Polar Year Experition has performed a difficult task in a most creditable manner and the extensive and valuable results obtained, as evidenced by the volumes under review, constitute a contribution of great value to students of geophysics.

K. L. SHERMAN

K. STUMPFF: *Grundlagen und Methoden der Periodenforschung.* Verlag von Julius Springer, 1937 (vii+332 mit 41 abb.). 24 cm. Preis: RM 39; geb. RM 42.

The ten years which have passed since Dr. Stumpff published his "Analyse periodischer Vorgänge" have been attended by an increasing interest in, and consideration of, two basic problems. These problems, which the mathematical theory of Fourier series leaves untouched, are (1) the technique of handling large masses of data expeditiously, and (2) the statistical treatment of the reality to be attributed to the results. The present work is not a revision of the former volume, but rather supplements it and, by referring the reader to the latter for details of certain numerical methods, the author has avoided needless repetition and left himself free to concentrate upon the two fundamental problems just mentioned.

To translate from the preface, "Not only have new methods for the solution of old problems by numerical or instrumental means been found, but also, out of the foundation of recent practical knowledge has appeared the possibility of clarifying the relation between different sorts of solutions from a more advanced point of view, and to utilize this knowledge in a unified formulation of the whole."

The representation of empirical series by orthogonal functions, and the allied

topics of interpolation and smoothing, open the way for a discussion of harmonic analysis from the purely formal side. The classical periodogram-methods, and variations, are then explained. Included in this is an extremely abbreviated description of the "punched-card method," using the Hollerith machine.

Toward the latter half of the book statistical considerations are introduced, first with the normal law of errors, and then with arbitrary distribution-functions. The main characteristics of two-dimensional distributions are outlined, for it is here that statistical theory makes contact with harmonic analysis. The author's own work on the expectancy for harmonic coefficients derived from series having auto-correlation is presented, followed by a review of the random-walk and harmonic-dial method which Bartels has developed and used so fruitfully. Especially at this point, the scarcity of diagrams illustrating the textual material is obvious and regrettable. Other methods, of more theoretical than practical importance, are dealt with in a separate chapter. The book concludes with a description of instrumental methods employing optical, mechanical, and electrical principles for seeking periods in large masses of data. This portion is illustrated with photographs of the several instruments devised by the author.

The bibliography of 163 items which appeared in "Analyse periodischer Vorgange" is now extended to include 319 references. Even now, this is a more or less selected list, not intended to be exhaustive. (The name of author for reference 229 should read "Schuster" and not "Schmidt.")

The author is director of the "Institut für Periodenforschung," which is affiliated with the Meteorological Institute of the University of Berlin. He is therefore in a particularly fortunate position to advance both the theoretical and the practical aspects of the subject.

To have available in one volume the material which Dr. Stumpff has collected and organized, including his own contributions, is a great advantage. The value of the book is enhanced further by the numerous passages interpreting the mathematical and statistical procedures.

J. W. Mauchly

NOTES

(See also page 300)

18. *New magnetic observatory in South Africa*—A Magnetic Branch of the Trigonometrical Survey Office at Cape Town has been recently established and Professor A. Ogg, of the University of Cape Town, has been appointed Magnetic Survey Adviser with Mr. Gotman as Technical Assistant. One may look forward now with assurance to the progress of terrestrial-magnetic investigations in South Africa. It is proposed to construct a magnetic observatory at a site removed from disturbances produced by electric railways at the present temporary site near Capetown. Thus permanence of the new observatory will be assured and the resolution of the Association of Terrestrial Magnetism and Electricity of the International Union of Geodesy and Geophysics in Lisbon in 1933 regarding a permanent South African observatory will be realized.

19. *British Arctic Expedition*—An expedition that will last three months left Leith, Scotland, for the arctic regions on June 27, 1937, to investigate the cosmic rays by means of balloons. Investigations will be made at very high altitudes within 10° of the north magnetic pole near Baffin Bay. J. M. Wordie, Senior Tutor of St. John's College, Cambridge, is the leader of the expedition.

20. *Magnetic Survey of the U. S. S. R.*—During the summer of 1936, the Bureau of General Magnetic Survey equipped and sent into the field 27 parties. Each party was supplied with instruments for absolute observations and a vertical-intensity variometer. The latter instrument served for observations at 2-km distances along the route and for determinations of the homogeneity of the magnetic field about the stations where absolute observations were made.

Contrary to the practice of previous years, the majority of the parties worked in remote regions where the routes could be traveled only on foot. Fourteen parties were sent to Kazakhstan, where, to some extent, automobile tractors were used to accelerate progress. Other parties worked in the Far East and in the Crimea where an extensive survey was executed permitting a study of possible changes in the character of the magnetic field and its secular change following the Crimean Earthquake. In accordance with an agreement with Chief Administration of the Northern Sea Route, observations were made along the shore of the Northern Frozen Ocean; two detailed surveys were made, namely, one in Karelia and one in Kazakhstan.

The programs of all parties included observations for determination of magnetic secular changes at repeat-stations; certain parties were especially designated for this purpose and worked in Transcaucasia and along the Volga and the navigable rivers of Siberia.

The Hydrographic Department of the Northern Sea Route Administration of the U. S. S. R., has issued, on the basis of magnetic observations made in 1934-35, an iosogonic chart of the Kara Sea.

After many years of interruption, continuous registration of the magnetic elements has been resumed at the Odessa and Tashkent observatories.

21. *Magnetic Survey of the United States*—A magnetic repeat-station was established at Fort Sill, Oklahoma, by S. A. Deel, temporary magnetic observer, to be used in connection with field-artillery orientation-problems. A similar station was established at Fort Bragg, North Carolina, by H. E. McComb. Mr. Deel completed field-work in the South Central States during the summer.

Additional diurnal-variation observations of declination were made by Dr. D. V. Guthrie of Louisiana State University and forwarded to this office.

Compass-declinometer observations were made at a number of places in Vermont by Professor Arthur D. Butterfield of the University of Vermont. Observations in the New England and Louisiana areas are of present importance due to the changing rate of change in these areas. The Arkansas Geological Survey is using a like instrument for declination-observations in Arkansas.

Lieut. Comdr. Harold A. Cotton took charge of the San Juan Magnetic Observatory on July 16, 1937, relieving Lieut. E. H. Bernstein. R. E. Gebhardt took charge of the Sitka Magnetic Observatory on June 1, 1937, relieving John Hershberger. John Hershberger took charge of the Tucson Magnetic Observatory on June 13, 1937, relieving J. W. Joyce, who has been ordered to Washington for duty in the office.

22. *Local attraction in Pacific Ocean*—An area of local attraction in the Pacific Ocean about 60 miles south of San Clemente Island, California, was investigated by the United States Coast and Geodetic Survey Ship *Pioneer*. In the preliminary work declinations varying from 11°.2 east to 18°.0 east were found in an area of about 200 square miles where the ocean-depths varied from 50 fathoms to 700 fathoms. The normal declination for that area is about 15° east.

23. *Zentralblatt für Geophysik, Meteorologie, und Geodäsie*—The section entitled "Geophysik" of the "Zentralblatt für Mathematik und ihre Grenzgebiete" appears beginning June 15, 1937, as "Zentralblatt für Geophysik, Meteorologie, und Geodäsie." The object of its editors is to publish as soon as possible abstracts of all articles dealing with the subjects in question. The abstracts will be printed in German, English, and French. In principle the "Zentralblatt" begins with the abstracts of articles appearing in 1937; however, abstracts of articles issued in 1936, which could not be published in Volume 15 of the "Zentralblatt für Mathematik," will appear in the new Journal. In order that the desired completeness may be attained, the editors urge authors to send reprints of their papers to the Zentralblatt für Geophysik, Meteorologie, und Geodäsie, Linkstrasse 22/24, Berlin W 9, Germany.

24. *Annual values for 1936 at De Bilt Observatory*—Dr. G. Van Dijk communicates the following mean values of the magnetic elements observed at De Bilt Observatory for the year 1936: D, 8° 21′.4 W; I, 67° 06′.9 N; H, 18236 gammas; Z, 43202 gammas; X, 18042 gammas; Y, −2650 gammas; F, 46893 gammas.

25. *Corrigenda*—The following changes should be made in the March 1937 number of the Journal: On page 95 the date of the storm recorded at the Cheltenham Magnetic Observatory as "*November 1*" should have been "*October 31*." On page 74 the legend in Figure 1 should read "30° south" instead of "30° north."

The following changes should be made in the June 1937 number of the Journal: On page 124 the entry in the third line of the first column of Table 1 should read "Sep 30" instead of "Sep 20." On page 125 the date of publication for the reference of foot-note 1 should read "Pavia, 1936" instead of "Pavia, 1935." On page 128 in the first line of the sixth paragraph read "constants" for "values" and in the third line of the same paragraph read "values" for "constants." On page 153 in the first line of the second paragraph read "Sir G. C. Simpson" for "Dr. G. S. Simpson." On page 161 in the eighth and ninth lines read "because" for "namely, that," and on page 162 in the fourteenth line read "Bruckshaw, and Broughton Edge and Laby" for "Bruckshaw, Broughton Edge, and Laby." On page 222 in the first line of the description of the storm of January 27 at the Huancayo Magnetic Observatory read "$08^h 37^m$" instead of "$03^h 37^m$."

26.—*Personalia*—Dr. *James B. Macelwane*, S. J., has been appointed Director of an Institute for Geophysics which has been established at the St. Louis University. It is planned that the Institute become a clearing house for geophysical records and related studies of structure of the Earth in the Central United States. Its inauguration was made possible by gifts from prominent residents of St. Louis.

Dr. *T. Thorkelsson*, Director of the Meteorological Service, Reykjavik, Iceland, has been appointed a member of the Committee on Registration in Iceland of Giant Pulsations of the Association of Terrestrial Magnetism and Electricity of the International Union of Geodesy and Geophysics. The other members of the Committee are D. la Cour (Chairman), S. Chapman, and J. A. Fleming.

Dr. *J. Bartels*, Director of the Geophysical Institute, University of Berlin, and Research Associate of the Carnegie Institution of Washington, is spending the summer at the Institution's Department of Terrestrial Magnetism in Washington, engaged in special work in terrestrial magnetism.

C. C. Ennis, who had been connected with the Department of Terrestrial Magnetism in the capacity of draftsman and expert computer since 1915, retired from active service on June 30, 1937. Mr. Ennis is well-known to the readers of this Journal through his frequent contributions. In recent years he has taken large part in editing publications of the Department and of articles published in this Journal.

We regret to record the death of Dr. *Joachim Scholz* on January 19, 1937, at the age of 34 years. Dr. Scholz was a zealous worker in atmospheric electricity and was in charge of this work during the Russian Scientific Expedition to Franz-Josef Land 1932-33, the results of which were published as Volume XVI of the "Transactions of the Arctic Institute of the U. S. S. R." (Leningrad 1935).

LIST OF RECENT PUBLICATIONS

By H. D. Harradon

A—Terrestrial and Cosmical Magnetism

Agematu, K., and S. Takahasi. Analysis of the records of the magnetic storms observed at the Kakioka Magnetic Observatory. Tokyo, J. Met. Soc., v. 15, No. 5, 1937 [207-210, (19)-(20)]. [Japanese text with English summary.]

Agostinho, J. Rapport sur l'activité du Service Météorologique des Açores dans le domaine de magnétisme terrestre depuis octobre 1933. Trans. Edinburgh Meeting 1936, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 10, Copenhagen, 1937 (53-54).

Athens, Greek Geodetic Commission. Rapport sur la mesure du magnétisme terrestre en Grèce. Athènes, Comm. Géod. Hellénique, 1936 (10 avec 4 fig. et 1 carte). 24 cm. [Report made to the Edinburgh Meeting of the Association of Terrestrial Magnetism and Electricty of the International Union of Geodesy and Geophysics, September, 1936.]

Batavia. Observations made at the Royal Magnetical and Meteorological Observatory at Batavia, v. 56, 1933. Published by order of the Government of the Netherlands Indies, by J. Boerema, Director. Batavia, 1937 (viii+85). 37 cm. [Contains magnetical records Batavia-Kuyper 1933; registered at Kuyper and reduced to the absolute values observed at Batavia.]

Besairie, H. Contribution à l'étude de la déclinaison magnétique à Madagascar et ses rapports avec la géologie. Tananarive, Ann. Géol., Service des Mines, Fasc. 7, 1937 (35-61). 28 cm.

Booth, E. H. A detailed magnetic survey as an aid to geological interpretation. District: Mittagong-Bowral. Sydney, N.S.W., J. Proc. R. Soc., v. 69, 1935 (35-60).

Some observations of zonal discordances in diurnal magnetic variations. Sydney, N.S.W., J. Proc. R. Soc., v. 70, 1937 (338-342).

Bossolasco, M. Sur la nature des perturbations magnétiques. Trans. Edinburgh Meeting 1936, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 10, Copenhagen, 1937 (331-335).

Memorandum sur la classification de la littérature de magnétisme terrestre suivant les sujets. Trans. Edinburgh Meeting 1936, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 10, Copenhagen, 1937 (436-439).

Bossolasco, M., and J. Egedal. Our knowledge of the lunar-diurnal variation of the magnetic declination and new results obtained from observations at Mogadiscio. Terr. Mag., Washington, D. C., v. 42, No. 2, 1937 (123-126).

Bouveng, E. Magnetic work, carried out by the Hydrographic Service of Sweden (Kungl. Sjökarteverket) in 1934 and 1935. Trans. Edinburgh Meeting 1936, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 10, Copenhagen, 1937 (132-133).

Bureau, R. Electricité atmosphérique et parasites atmosphériques. Trans Edinburgh Meeting 1936, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 10, Copenhagen, 1937 (429-436).

Chapman, S., and D. la Cour. Proposal for the establishment in Iceland of temporary stations for quick-run magnetic registration. Trans. Edinburgh Meeting 1936, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 10, Copenhagen, 1937 (441-443).

Critikos, N. A. Phénomènes météorologiques et magnétiques. Beitr. Geophysik, Leipzig, Bd. 50, Heft 1, 1937 (18-21). [Observations faites près d'Athènes pendant l'éclipse totale du soleil du 19 juin 1936.]

De Bilt, Meteorological and Magnetical Observatory. Annuaire. Quatre-vingt-septième année 1935. B, Magnétisme terrestre. (K. Nederlandsch Met. Inst. No. 98.) 's-Gravenhage, 1936 (vi+24). 34 cm.

Dijk, G. van. Rapport sur les travaux magnétiques 1933-1936. Trans. Edinburgh Meeting 1936, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 10, Copenhagen 1937 (109-111). [The report applies to work done in Holland during 1933-1936.]

Rapport sur la publication du caractère magnétique numérique des jours. Trans. Edinburgh Meeting 1936, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 10, Copenhagen, 1937 (163-164).

Rapport sur la publication des caractères magnétiques pendant l'Année Polaire 1932-1933. Trans. Edinburgh Meeting 1936, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 10, Copenhagen, 1937 (218-220).

Egypt, Physical Department. Meteorological report for the year 1933. Cairo, Ministry of Public Works, Physical Dept., 1937 (xiv+219). 32 cm. [Contains values of the magnetic elements at Helwan Observatory for 1933.]

Everdingen, E. van. Report on international magnetic classification of Greenwich days prior to 1906. Trans. Edinburgh Meeting 1936, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 10, Copenhagen, 1937 (237-238).

Fleming, J. A. Report of the Department of Terrestrial Magnetism, Carnegie Institution of Washington, to the Edinburgh Assembly on work done since the Lisbon Assembly. Trans. Edinburgh Meeting 1936, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 10, Copenhagen, 1937 (142-157).

Report of committee to consider existing and desirable distribution of magnetic and electric observatories and the better coordination of work and publications of existing observatories. Trans. Edinburgh Meeting 1936, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 10, Copenhagen, 1937 (164-174).

Report of the committee for study of relation between solar activity and terrestrial magnetism. Trans. Edinburgh Meeting 1936, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 10, Copenhagen, 1937 (187-189).

Progress-report of the joint committee of the Commission of Terrestrial Magnetism and Atmospheric Electricity of the International Meteorological Organization and the Association on methods and codes to adequately describe magnetic disturbances and perturbations. Trans. Edinburgh Meeting 1936, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 10, Copenhagen, 1937 (222-234). [Contains appendices as follows: (1) Suggestions on methods of adequately describing magnetic disturbances and supplementary suggestions after receiving comments by Messrs. Chapman and Sucksdorff, by A Nippoldt; (2) Comments on Dr. Nippoldt's suggestions of February 27, 1936, by S. Chapman; (3) Comments on Dr. Nippoldt's suggestions of February 27, 1936, by E. Sucksdorff; (4) Comments regarding uniform methods and codes to adequately describe magnetic records, by A. G. McNish; (5) International code and agreement for descriptions of magnetic conditions, by H. F. Johnston; (6) Comments regarding uniform methods and codes to adequately describe magnetic records, by N. H. Heck.]

Intercomparisons of magnetic standards and control of standards. Trans. Edinburgh Meeting 1936, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 10, Copenhagen, 1937 (241-248).

Fleming, J. A., and C. C. Ennis. Latest annual values of the magnetic elements at observatories. Trans. Edinburgh Meeting 1936, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 10, Copenhagen, 1937 (323-330).

Forbush, S. E., and E. A. Johnson. Results of international comparisons of magnetic horizontal intensity with CIW sine-galvanometer 1. Trans. Edinburgh Meeting 1936, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 10, Copenhagen, 1937 (248-259).

Gallo J. Observations at secular-variation stations in Mexico during 1936. Terr. Mag., Washington, D. C., v. 42, No. 2, 1937 (217-218).

GOLDIE, A. H. R. The electric current-systems of magnetic storms. Terr. Mag., Washington, D. C., v. 42, No. 2, 1937 (105-107).

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ÜBER DIE METHODE VON ARTHUR SCHUSTER ZUR ANALYTISCHEN DARSTELLUNG NUMERISCH GEGEBENER FUNKTIONEN AUF DER KUGELFLÄCHE

VON ADOLF SCHMIDT

Abstract—A. Schuster's method for calculating the coefficients in the development of a given function into a series of spherical harmonics reduces the computation to ordinary harmonic analysis; the sine and cosine terms with the multiples of the co-latitude as arguments are, once for all, developed into spherical harmonics. For this development, two possibilities offer themselves, the one leading to finite series, the other, chosen by Schuster, leading to infinite series. The reasons for this choice are discussed. Certain objections to the method are found justified, namely, that its application should be restricted to cases in which the given function is known with equal accuracy all over the surface of the globe instead of being represented—as in most geophysical applications—by insufficient data in the polar areas or in the Southern Hemisphere. Formulae for practical calculations and an extract from Schuster's tables, for use with normalized harmonics, are given.

In einer gross angelegten, inhaltreichen Abhandlung[1] hat A. Schuster am Schlusse[2] als Anwendung der erhaltenen Ergebnisse eine Methode zur Darstellung gegebener Funktionen auf der Kugelfläche entwickelt, der er einen wesentlichen Vorzug gegenüber anderen Verfahren,—besonders denen, die sich der Methode der kleinsten Quadrate bedienen,—zuschreibt. Meines Erachtens unterliegt aber Schusters Vorschlag einem gewichtigen Bedenken, das ich in der ihm gewidmeten Besprechung in den Erläuterungen zu den von mir herausgegebenen "Tafeln der normierten Kugelfunktionen" (p. 16) kurz angedeutet habe.[3] Da es sich um eine Frage von prinzipieller Bedeutung handelt, glaube ich mich der Verpflichtung nicht entziehen zu dürfen, mein Bedenken unter eingehender Begründung wiederholen zu sollen. Dass ich dies nicht schon früher, bei Lebzeiten Schusters, getan und diesem dadurch Gelegenheit gegeben habe, Stellung dazu zu nehmen, erklärt sich daraus, dass ich selbst erst auf die Sache aufmerksam wurde, als ich daran ging, a. a. O. eine Beschreibung des Verfahrens zu geben.

Im Folgenden ist Schusters Bezeichnungsweise benutzt, die zur Erleichterung der Vergleichung hier mit der in den genannten Tafeln angewandten zusammengestellt sei.

$$\text{Schuster:}\quad \theta,\ \phi,\ n,\ \sigma,\ k, K$$
$$\text{Tafeln:}\quad u,\ t,\ n,\ m,\ c,\ s$$

Die von Schuster aus rechnerischen Zweckmässigkeitsgründen (vgl. dazu die Bemerkung auf p. 208) benutzten Funktionen R_m^n stehen zu den

[1] On some definite integrals and a new method of reducing a function of spherical coordinates to a series of spherical harmonics. Phil. Trans., R. Soc., A **200**, 181-223 (1903).
[2] §II. Application of the previous results to the expression of functions by means of a series of spherical harmonics, p. 205 sq.
[3] Vergl. das Referat von J. Bartels in Terr. Mag., **41**, 264 (1936).

in den Tafeln und übereinstimmend damit im Folgenden angewandten P_n^m in der Beziehung

$$R_m^n\ (\cos\ \theta) = P_n^m\ (\cos\ \theta)\sqrt{2n+1}$$

Demgemäss sind die hier auftretenden Reihenkoeffizienten g_n^σ und h_n^σ das $\sqrt{2n+1}$ fache der ebenso bezeichneten bei Schuster.

A

Eine skalare Funktion des Ortes $F\ (\theta,\ \phi)$ auf der Kugelfläche sei zahlenmässig durch ihre Werte an einer Anzahl von Punkten gegeben, die sich auf die zu den Werten $\theta_1,\ \theta_2\ \ldots\ \theta_q$ des Polabstands gehörigen Parallelkreise verteilen und die hinreichend dicht liegen, damit sich auf jedem dieser Kreise F durch eine Fouriersche Reihe von der Form

$$\begin{aligned} &k^0 + k^1\ \cos\phi + k^2\ \cos 2\phi + \ldots + k^\sigma\ \cos\sigma\phi + \ldots \\ &\quad + K^1\ \sin\phi + K^2\ \sin 2\phi + \ldots + K^\sigma\ \sin\sigma\phi + \ldots \end{aligned}$$

darstellen lässt.

Die q Zahlenwerte eines jeden Koeffizienten k^σ oder K^σ sind nunmehr linear durch die sogenannten zugeordneten Funktionen P_n^σ (cos θ) auszudrücken

$$\begin{aligned} k^\sigma &= g_\sigma^\sigma\ P_\sigma^\sigma + g_{\sigma+1}^\sigma\ P_{\sigma+1}^\sigma + \ldots + g_{\sigma+q-1}^\sigma\ P_{\sigma+q-1}^\sigma \\ K^\sigma &= h_\sigma^\sigma\ P_\sigma^\sigma + h_{\sigma+1}^\sigma\ P_{\sigma+1}^\sigma + \ldots + h_{\sigma+q-1}^\sigma\ P_{\sigma+q-1}^\sigma \end{aligned}$$

und man erhält zur Bestimmung der je q darin auftretenden Faktoren g_n^σ und h_n^σ je ein System von q linearen Gleichungen, das man im allgemeinen nach der Methode der kleinsten Quadrate auflösen wird. Soll die Berechnung sämtliche Unbekannten bis zu denen mit $\sigma = q$ umfassen, so gewährt die Methode von Fr. Neumann eine wesentliche Erleichterung und Abkürzung der Rechnung (vgl. a. a. O., pp. 14, 15).

Von besonderer Wichtigkeit ist der Fall, dass F ein Potential V bezeichnet, das nicht selbst gegeben ist, sondern von dem man eine Komponente seines Gradienten kennt, die meridionale X oder die longitudinale Y

$$X = \partial V/\partial\theta \qquad Y = -(1/\sin\ \theta)(\partial V/\partial\phi)$$

Die Rechnung verläuft hier genau ebenso wie zuvor, wenn man ausser dem Zahlentafeln der Funktionen P_n^m auch solche für $\partial P_n^m/\partial\theta$ und $mP_n^m/\sin\theta$ zur Verfügung hat. Die in den T. d. n. K. enthaltenen Werte sind unter der Bezeichnung X_n^m und Y_n^m aus rechnerischen Zweckmässigkeitsgründen mit dem Faktor $1/n$ multipliziert. Auf die besondere Tafel für Y_n^m kann man überdies verzichten, wenn man Y sin θ nach den P_n^m entwickelt.

Vom Gebrauch aller dieser Tafeln kann man bei der Entwicklung von F, X, Y Abstand nehmen und ihn auf die umgekehrte Aufgabe der Auswertung der erhaltenen Reihen beschränken, wenn man mit Schuster nach der Darstellung der Funktion auf den einzelnen Parallelkreisen die Koeffizienten k und K wiederum zunächst in Fouriersche Reihen entwickelt und diese nachträglich in Kugelfunktionenreihen transformiert, selbstverständlich, wenn X gegeben ist, nach Ableitung von V aus X durch Integration.

Im Folgenden soll nur die Entwicklung von F behandelt werden,

da nach dem soeben Gesagten diejenige von X und Y nichts Neues bietet. Ferner aber soll die Betrachtung auf den einfachsten, den zonalen, Fall ($\sigma=0$) beschränkt werden, denn in diesem kommt die hier zur Diskussion stehende Frage bereits vollständig zur Erörterung.

B

Es handelt sich somit ausschliesslich um die Entwicklung von k^0. Sie ist von wesentlich anderer Bedeutung, formaler als diejenige von F auf den einzelnen Parallelkreisen. Der Parallelkreis ist ein homogenes Gebilde, dessen Punkte untereinander vollkommen gleichwertig oder gleichberechtigt sind und das Intervall von 0 bis 2π erfüllen. Die darstellende trigonometrische Entwicklung ist eindeutig bestimmt in Bezug auf einen willkürlich wählbaren Ausgangspunkt der Koordinate ϕ. Das Intervall, auf das sich die Grössen k und K beziehen, der Halbmeridian, umspannt dagegen die Werte von 0 bis π mit Einschluss nur einer Grenze oder des Mittelwertes beider Grenzen. (Man kann es natürlich auch erweitert denken, so dass es den ganzen Meridian umspannt, wodurch der Punkt (θ, ϕ) zum Punkte $(2\pi-\theta, \pi+\phi)$ wird. Wir betrachten dann die Kugelfläche als eine zweiblättrige Riemannsche Fläche deren Blätter in den beiden Polen zusammenhängen. Für den Zweck der numerischen Berechnung dürfen wir hiervon absehen). Die einzelnen Punkte des Halbmeridians sind nicht gleichwertig; insbesondere nehmen die Pole, an denen unter Umständen Unstetigkeiten zu beachten sind, eine Ausnahmestellung ein. Damit hängt es zusammen, dass es, wie schon Fr. Neumann betont hat, nicht zweckmässig wäre, bei der Entwicklung von k^σ bei der Darstellung durch Fouriersche Reihen stehen zu bleiben, sondern dass man zur Entwicklung nach Kugelfunktionen fortschreiten muss. Erst die letzteren besitzen eine mathematisch und physikalisch bemerkenswerte Bedeutung.

Im Gegensatz zur Entwicklung auf dem Vollkreise ist diejenige auf dem Halbkreise nicht eindeutig bestimmt. Sie kann nach Belieben durch eine Sinusreihe oder durch eine Kosinusreihe erfolgen und daher auch aus beiden zusammengesetzt sein. Besitzt die betrachtete Funktion an dem als Nullpunkt gewählten Pole einen von null verschiedenen Wert, so empfiehlt es sich, ihren Überschuss über diesen als F anzusehen. Man kann also, ohne die Allgemeinheit zu gefährden, für $\theta=0$ auch $k^0=0$ annehmen. Hieraus und aus den Werten an den zwischen $\theta=0$ und $\theta=\pi$ liegenden q Punkten mögen sich für k^0 die beiden Reihen ergeben, bei deren erster die streng zu erfüllende Bedingungsgleichung zu beachten ist

(I) $\quad a_0+a_1 \cos \theta+ \ldots +a_p \cos p\theta+ \ldots +a_q \cos q\theta \quad \text{mit } \Sigma a_p=0$
(II) $\quad b_1 \sin \theta+ \ldots +b_p \sin p\theta+ \ldots +b_q \sin q\theta$

Die zwei Reihen sind nicht identisch. Sie liefern zwar für $\theta_1, \theta_2 \ldots \theta_q$ sowie für $\theta=0$, aber im allgemeinen nicht für die dazwischen liegenden Werte von θ, denselben Wert. Im Zusammenhang damit führen sie auch auf zwei verschiedene Kugelfunktionenreihen, und zwar auf eine endliche und eine konvergente unendliche.

Die erste ergibt sich aus (I) ohne Schwierigkeit. Für P_n^0 (cos θ), das mit der Legendreschen Kugelfunktion einer Veränderlichen P^n—hier besser P_n geschrieben—identisch ist, findet man den allgemeinen Ausdruck bei Heine p. 45.

Danach ist speziell

$P_0=1,\ P_1=\cos\theta,\ P_2=(3\cos 2\theta+1)/4,\ P_3=(5\cos 3\theta+3\cos\theta)/8,$
$P_4=(35\cos 4\theta+20\cos 2\theta+9)/64,\ P_5=(63\cos 5\theta+35\cos 3\theta+30\cos\theta)/128$

Durch Umkehrung der vorausgehenden Formeln ergeben sich die Werte der $\cos n\theta$ als lineare Aggregate der P_n. Der allgemeine Ausdruck ist ziemlich kompliziert. Man findet ihn in dem bekannten Buche von Byerly[4] (p. 182) und in Schusters Arbeit (p. 206). Bei Heine[5] (p. 50) ist nur der Gang der Entwicklung angegeben. Speziell ist

$$1=P_0,\quad \cos\theta=P_1,\quad \cos 2\theta=(4\,P_2-P_0)/3,\quad \cos 3\theta=(8P_3-3\,P_1)/5,$$
$$\cos 4\theta=(192\,P_4-80\,P_2-7\,P_0)/105,\quad \cos 5\theta=(128\,P_5-56\,P_3-9\,P_1)/63$$

Setzt man nun diese Ausdrücke in (I) ein, so erhält man als Koeffizienten der Funktionen P_n die abbrechenden Reihen

$$(\mathrm{III}\ a)\begin{cases} g_0{}^0=a_0-(1/3)\,a_2-\ (1/15)\,a_4-\ \ldots, & g_1{}^0=a_1-(3/5)\,a_3-(1/7)\,a_5-\ \ldots \\ g_2{}^0=\qquad (4/3)\,a_2-(16/21)\,a_4-\ \ldots, & g_3{}^0=\qquad (8/5)\,a_3-(8/9)\,a_5-\ \ldots \\ g_4{}^0=\qquad\qquad (64/35)\,a_4-\ \ldots, & g_5{}^0=\qquad\qquad (128/63)\,a_5-\ \ldots \end{cases}$$

Die hierdurch definierte, mit P_q abbrechende Darstellung von k^0 mittels einer Kugelfunktionenreihe ist identisch mit der trigonometrischen Reihe (I), aus der sie ja durch einfache lineare Umrechnung hervorgegangen ist.

Das geschilderte Verfahren erscheint als durchaus sachgemäss und dem Zweck der Darstellung empirischer Grössen angemessen. Das gilt auch dann noch, wenn man die Anzahl der Koeffizienten a_p in (I) kleiner als q wählt, so dass man es mit einer Ausgleichungsrechnung zu tun hat.

Entsprechend verhält es sich im allgemeinen Falle, d. h. bei der Darstellung von k^σ und K^σ, wenn man unter (I) bei geradem σ die Kosinusreihe, bei ungeradem σ die Sinusreihe versteht und in jedem Falle die Entwicklung nach den Funktionen $P_n{}^\sigma$ vornimmt.

Von ganz anderer Art ist die Lösung, die sich ergibt, wenn man, wie es Schuster tut, von (II) ausgeht. Den dazu nötigen allgemeinen Ausdruck zur Darstellung von $\sin p\theta$ durch Kugelfunktionen findet man im Handbuch der Kugelfunktionen von E. Heine (p. 46) und bei Schuster (§8) sowie bei Byerly (p. 182).

Die ersten Sonderfälle ergeben

$$\begin{aligned} \sin\ \theta &= 0.78540\,P_0-0.49087\,P_2-0.11045\,P_4-\ \ldots \\ \sin 2\theta &= 1.1781\ \ P_1-0.68722\,P_3-0.16874\,P_5-\ \ldots \\ \sin 3\theta &= 1.4726\ \ P_2-0.82835\,P_4-0.20939\,P_6-\ \ldots \\ \sin 4\theta &= 1.7181\ \ P_3-0.94493\,P_5-0.24160\,P_7-\ \ldots \\ \sin 5\theta &= 1.9328\ \ P_4-1.0469\ \ P_6-0.26893\,P_8-\ \ldots \end{aligned}$$

Durch Einsetzung in (II) folgt hieraus

$$(\mathrm{III}\ b)\begin{cases} g_0{}^0=0.7854\,b_1, & g_1{}^0=1.1781\,b_2, \\ g_2{}^0=-0.4909\,b_1+1.4726\,b_3, & g_3{}^0=-0.6872\,b_2+1.7181\,b_4, \\ g_4{}^0=-0.1105\,b_1-0.8284\,b_3+1.9328\,b_5, & g_5{}^0=-0.1687\,b_2-0.9449\,b_4+2.126 \end{cases}$$

(Beim Vergleich dieser Zahlen mit den in Schusters Tabellen für den Fall $\sigma=0$ angegebenen ist zu beachten, dass letztere durchweg mit

[4] W. E. Byerly, An elementary treatise on Fourier's series and spherical, cylindrical, and ellipsoidal harmonics, Boston, Ginn and Co., 1893.

[5] E. Heine, Handbuch der Kugelfunktionen, Band 1, Berlin, G. Reimer, 1878.

$\sqrt{2n+1}$ zu multiplizieren sind, weil Schuster, wie schon bemerkt, die Funktionen R_n^m benutzt hat. In den Formeln für die g_n^σ (p. 209) beachte man ferner, dass man für v_n^σ, u_n^σ eigentlich $v_{p,p,}{}^\sigma{}_n$, $u_{p,}{}^\sigma{}_n$ zu lesen hat.) Hier ergibt sich also nicht wie im anderen Fall eine geschlossene, sondern eine ins Unendliche fortlaufende Entwicklung: das System der Einzelwerte von k^0 ist, ebenso wie (II) äquivalent mit $\lim_\infty$ (III b).

Am anschaulichsten zeigt sich der Gegensatz der beiden Darstellungsweisen in dem einfachsten Falle, dem des homogenen Feldes $F=k^0=c\cos\theta$.

Das System (IIIa) der Koeffizienten a_p reduziert sich hier auf $g_1{}^0=a_1=c$, und man hat $F=cP_1$.

Das System der (IIIb) wird, da

$$\cos\theta=\frac{4}{\pi}\left(\frac{2}{1.3}\sin 2\theta+\frac{4}{3.5}\sin 4\theta+\frac{6}{5.7}\sin 6\theta+\ldots+\frac{2s}{(2s-1)(2s+1)}\sin 2s\theta+\ldots\right)$$

ist, zu

$$b_1=0,\quad b_3=0,\quad \ldots\ldots,\quad b_{2s+1}=0,$$
$$b_2=0.8482c,\quad b_4=0.33953c,\quad b_6=0.21827c,\ \ldots$$

Hieraus ergibt sich nach (IIIb)

$$g_0{}^0=g_2{}^0=\ \ldots\ =0,\quad g_1{}^0=c,$$

$g_3{}^0=(-0.5832+0.5833)\,c=0,\quad g_5{}^0=(-0.1434-0.3208+0.4641)\,c=0,\ldots$ und somit, wie es sein muss, $F=cP_1$.

Der Entwicklung liegt ja die Festsetzung der b_p zugrunde, und zwar in analytischer Form, also allgemein für das ganze Intervall von 0 bis π gültig, Anders aber verhält es sich –und daraus entspringt das zu Anfang erwähnte Bedenken—wenn k^0 numerisch durch seine Werte für eine begrenzte Zahl q von Parallelkreisen definiert ist. Berechnet man aus diesen die Koeffizienten b_i oder ausgleichend nur die ersten p unter ihnen, so nimmt man damit stillschweigend an, dass die weiteren Koeffizienten der unendlichen Reihe (II) gleich Null sind, genauer gesagt, dass der durch sie bestimmte Rest der unendlichen Reihe auf jedem der q Parallelkreise zu Null wird. Damit hört (II) auf, mit (I) vollständig übereinzustimmen. Es fehlt deshalb auch die bei (I) bestehende völlige Äquivalenz mit der begrenzten durch Ausgleichung der beobachteten k^0-Werte abzuleitenden P-Reihe, die wegen der bekannten Eigenschaften der Kugelfunktionen als die massgebende Darstellung der Werteverteilung auf der Kugelfläche zu gelten hat.

Das hervorgehobene Bedenken verliert daher umso mehr an Gewicht, je vollständiger die Beobachtungsgrundlage ist, so vor allem gänzlich, wenn sich diese gleichmässig über die ganze Kugelfläche erstreckt, und die einzelnen Koeffizienten a_i und b_i also durch Integration über diese Fläche gewonnen werden, und auch schon dann, wenn die Werte von θ_1, θ_2, . . . gleichabständig über das Intervall 0 bis π verteilt sind, was Schuster als selbstverständlich vorauszusetzen scheint.

Gerade bei geophysikalischen Anwendungen ist aber diese Bedingung meistens nicht erfüllt. Vor allem fehlt es gewöhnlich an hinreichenden Beobachtungen aus den Polargebieten, und ausserdem ist die südliche Halbkugel fast immer sehr viel schwächer vertreten, als die nördliche. Das von Schuster empfohlene Aushilfsmittel der interpolatorischen Ableitung äquidistanter Werte versagt hier leicht und ist überdies ziemlich mühsam, wenn höhere Ansprüche an die Genauigkeit gestellt werden.

C

Was hat nun Schuster veranlasst, sein Verfahren zu entwickeln und sich der grossen Mühe zu unterziehen, die für seine Anwendung unerlässlichen umfangreichen Hilfstafeln, die er bis zur 12. Ordnung ausdehnt, zu berechnen? Warum zieht er insbesondere den mathematisch übrigens interessanteren Weg (II) dem trivialen (I) vor? Er sagt darüber (p. 205):

"All methods which have been applied so far, suffer from the serious inconvenience that the method of the least squares is applied in such a way as to make the value of the coefficients of lower degrees depend on the number of terms which are taken into account. That is to say, the coefficients are not independent of each other as they ought to be.

"A method suggested by F. E. Neumann, which is free from this defect, introduces other complications, and has never, as far as I know, been applied in practice.

"The theorem of §8 offers a simple solution of the practical difficulties, and reduces the whole problem to an expansion by means of Fourier's analysis, which can be carried out either by the well-known process of calculation, or by mechanical means."

Weiterhin (§12) wird noch betont, dass das Verfahren besonders vorteilhaft ist, wenn es sich darum handelt, ein Potential aus einem seiner Differentialquotienten, besonders aus dem meridionalen, zu berechnen. Diese Aufgabe hat vermutlich Schuster überhaupt den Anstoss zu seinen Betrachtungen gegeben, ist aber seiner Methode nicht eigentümlich, denn sie kann ebenso im Anschluss an die Entwicklung nach (I) behandelt werden.

In dem, was an der M. d. k. Q. bemängelt wird, liegt gerade bei sachgemässer Anwendung ihr Vorzug. Die hier im Gegensatz zu ihr aufgestellte formale Forderung widerspricht der Absicht der Ausgleichung und ist im vorliegenden Falle damit nur vereinbar, wenn die Ausgleichung bereits bei der trigonometrischen Reihenentwicklung erfolgt ist. Soll sie hier aber von der Ausdehnung der Reihe (sollen, wie Schuster es ausdrückt, die einzelnen Koeffizienten von einander) unabhängig sein, so müssen die Beobachtungen gleichmässig über das ganze Gebiet verteilt liegen. Damit kommen wir wieder auf die von einem andern Gesichtspunkte aus als notwendig erkannte Bedingung zurück.

Ist diese Bedingung aber erfüllt, so ergibt sich, wie ein Blick auf (III*b*) zeigt, durch das von (II) ausgehende Verfahren eine gewisse Abkürzung der Rechenarbeit, die umsomehr ins Gewicht fällt, je geringer die Zahl der für theoretische geophysikalische Zwecke meistens allein gesuchten Anfangskoeffizienten ist, denn man braucht nur die gleiche Anzahl von Koeffizienten der trigonometrischen Reihe zu berechnen.

Nach (III*a*) hat man dagegen sämtliche Koeffizienten der (allerdings durch die vorangegangene Ausgleichung verkürzten) Reihe (I) zu berücksichtigen.

Es entspricht daher der von Schuster zwar nicht ausdrücklich betonten, aber seiner Darstellung stillschweigend zugrunde gelegten Voraussetzung, wenn man die Anwendung seiner Methode im allgemeinen auf die Fälle beschränkt, in denen die Beobachtungsdaten von vornherein gleichmässig über die Kugelfläche verteilt sind. Dazu gehört insbesondere ihre Anordnung auf Parallelkreisen, die den Meridian gleichmässig einteilen.

m ungerade, $\cos p\theta = u^m_{m,p}\ P^m_m(\theta) + u^m_{m+1,p}\ P^m_{m+1}(\theta) + \ldots$ mit $u^m_{n,p} = 0$ für $n \leq (p-2)$, und ausserdem für $(n+p)$ gerade

	n	p = 1	p = 3	p = 5	p = 7	p = 9	n	p = 0	p = 2	p = 4	p = 6	p = 8
	2	+0.85022	-0.85022	....	....	....	1	+1.1781	-0.58905	....	....	....
	4	+0.34926	+0.87316	-1.22242	....	....	3	+0.42084	+0.84167	-1.05209	....	....
	6	+0.22846	+0.31984	+0.95954	-1.50784	....	5	+0.26141	+0.32676	+0.91493	-1.37239	....
	8	+0.17113	+0.20536	+0.32271	+1.04881	-1.74802	7	+0.19024	+0.21307	+0.31961	+1.00449	-1.63229
5	4	+0.92408	-1.38609	+0.46203	....	....	3	+1.62989	-1.08660	+0.27164	....	....
	6	+0.65021	+0.21674	-1.66166	+0.79471	....	5	+0.84706	+0.49412	-1.55294	+0.63529	....
	8	+0.49852	+0.33235	-0.11078	-1.80021	+1.08013	7	+0.59312	+0.47450	+0.02636	-1.73982	+0.94241
	6	+0.92801	-1.67043	+0.92801	-0.18560	....	5	+1.89408	-1.42056	+0.56822	-0.09470	....
	8	+0.77349	-0.30940	-1.54699	+1.46964	-0.38674	7	+1.09287	+0.17486	-1.66115	+1.22401	-0.28415
7	8	+0.91521	-1.83042	+1.30745	-0.45761	+0.06537	7	+2.08506	-1.66805	+0.83402	-0.23829	+0.02979

m gerade, $\sin p\theta = v^m_{m,p}\ P^m_m(\theta) + v^m_{m+1,p}\ P^m_{m+1}(\theta) + \ldots$ mit $v^m_{n,p} = 0$ für $n \leq (p-2)$, und ausserdem für $(n+p)$ gerade

	n	p = 1	p = 3	p = 5	p = 7	p = 9	n	p = 0	p = 2	p = 4	p = 6	p = 8
	0	+0.78540	....	....	....	....	1	....	+1.17810	....	....	....
	2	-0.49087	+1.47262	....	....	....	3	....	-0.68722	+1.71806	....	....
	4	-0.11045	-0.82835	+1.93281	....	....	5	....	-0.16874	-0.94493	+2.12609	....
	6	-0.04985	-0.20939	-1.04694	+2.30327	....	7	....	-0.08053	-0.24160	-1.13898	+2.46779
	8	-0.02852	-0.10268	-0.26893	-1.22361	+2.62203						
2	2	+1.27533	-0.42511	....	....	....	3	....	+1.33080	-0.66540	....	....
	4	+0.24697	+1.35832	-0.86438	....	....	5	....	+0.34581	+1.38324	-1.03743	....
	6	+0.10837	+0.39735	+1.40879	-1.19206	....	7	....	+0.16776	+0.42872	+1.43528	-1.33276
	8	+0.06136	+0.20455	+0.45000	+1.46250	-1.46250						
	4	+1.63353	-0.81676	+0.16335	....	....	5	....	+1.49740	-1.19792	+0.29948	....
	6	+0.59356	+1.22669	-1.46411	+0.43528	....	7	....	+0.78687	+0.96172	-1.66116	+0.56829
	8	+0.32179	+0.81521	+0.72940	-1.81277	+0.69722						
	6	+1.87527	-1.12516	+0.37505	-0.05358	....	7	....	+1.56031	-1.56031	+0.66871	-0.11145
	8	+0.83547	+1.00256	-1.76642	+0.94289	-0.17903						
	8	+2.05922	-1.37282	+0.58835	-0.14709	+0.01634						

D

Um die Anwendung der Methode von Arthur Schuster, dessen Abhandlung mit ihren bis zur 12. Ordnung reichenden Tabellen vielfach schwer zugänglich sein dürften, zu erleichtern, stelle ich hier die dazu nötigen Angaben in gebrauchsfertig ausführlicher Form zusammen, allerdings, was fast immer genügen wird, unter Beschränkung auf die 5 ersten Ordnungen und Verkürzung der auf die Funktionen P_n^σ umgerechneten Zahlen um zwei Dezimalen. Die Anordnung der Formeln entspricht genau derjenigen in Schusters auf die R_m^n bezogenen Tafeln, so dass auch diese damit ohne weitere Erläuterung verständlich werden. Wer mit diesen rechnet, erhält die für die Funktionen R_m^n geltenden Koeffizienten g_n^σ und h_n^σ und hat, um sie auf die P_n^σ umzurechnen, mit $\sqrt{2n+1}$ zu multiplizieren.[6]

Der Gang der Rechnung vollzieht sich in drei Schritten.

(1) Entwicklung der Zahlenwerte von F auf den einzelnen Parallelkreisen nach ϕ in Fouriersche Reihen. Die zum Polabstand θ_i gehörige Reihe sei

$$\begin{aligned} F(\theta_i) = k_i^0 + k_i^1 \cos\phi + \ldots + k_i^\sigma \cos\sigma\phi + \ldots \\ + K_i^1 \sin\phi + \ldots + K_i^\sigma \sin\sigma\phi + \ldots \end{aligned}$$

Hinsichtlich der Verteilung der θ_i kommen nur zwei Fälle ernstlich in Betracht: entweder $\theta_i = i\pi/q$ mit $i=1, 2, \ldots (q-1)$ nebst den beiden mit halbem Gewicht zu berücksichtigenden Polen ($i=0$, $i=q$); oder $\theta = j\pi/2q$ mit $j=1, 3, \ldots (2q-1)$.

Schuster berücksichtigt nur den ersten Fall. Der zweite ist aber mindestens ebenso wichtig und hat den Vorteil, dass er die an den Polen auftretenden formalen Schwierigkeiten umgeht, wie dies auch die Methode von Fr. Neumann tut. (Die dieser von Schuster zugeschriebenen "inconveniences" sind mir unerfindlich.)

(2) Entwicklung der k^σ und K^σ nach θ in Fouriersche Reihen. Sie geschieht bei ungeradem σ in der Form

$$k^\sigma = a^\sigma + a_1^\sigma \cos\theta + \ldots + a_p^\sigma \cos p\,\theta + \ldots + a_q^\sigma \cos q\,\theta,$$

bei geradem σ in der Form

$$k^\sigma = \qquad b_1^\sigma \sin\theta + \ldots + b_p^\sigma \sin p\,\theta + \ldots + b_q^\sigma \sin q\,\theta$$

im Gegensatz zu dem, was man geneigt sein kann, zunächst zu erwarten. Darin liegt gerade das Eigenartige und mathematisch Reizvolle der Methode.

In gleicher Weise ist K^σ zu entwickeln, was auf die Koeffizienten α und β an Stelle von a and b führen möge.

(3) Berechnung der Koeffizienten g_n^σ und h_n^σ des Ausdrucks

$$F(\theta, \phi) = \sum_0^q{}^\sigma \sum_\sigma^q{}^n \; P_n^\sigma(\cos\theta)\,(g_n^\sigma \cos\sigma\phi + h_n^\sigma \sin\sigma\phi)$$

nach den hier folgenden Formeln für die g_n^σ und den entsprechenden α, β statt a, b enthaltenden für die h_n^σ.

[6] Zur Auswertung von $F(\theta, \phi)$ kann man natürlich auch seine Darstellung in den R_m^n benutzen. 5stellige Logarithmen dieser Funktionen der ersten 5 Ordnungen von 5° zu 5° habe ich in Terr. Mag. (1, pp. 75-76, 1896) mitgeteilt. Ich benutze die Gelegenheit, zwei darin stehen gebliebene Fehler zu berichtigen; es muss heissen bei 40°, log $R_6^3 = 8.82452n$, und bei 55° log $R_6^6 = 9.45917n$.

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THE HEATING OF THE IONOSPHERE BY THE ELECTRIC CURRENTS ASSOCIATED WITH GEOMAGNETIC VARIATIONS

By S. Chapman

§1. The transient geomagnetic variations (periodic and irregular) appear to be due mainly to primary electric currents flowing somewhere in the ionosphere, and in smaller degree to secondary currents induced within the Earth by the primary currents. These currents must heat the medium in which they flow, and the purpose of this note is to estimate the magnitude of this heating in the ionosphere.

§2. Schuster in his important 1907 memoir on S, the solar daily magnetic variation, remarked as follows on the heating of the atmosphere associated with S[1]:

"One further consequence of the theory deserves to be noticed. The electric currents indicated by our theory are sufficiently large to produce a sensible heating effect in the low-pressure regions through which they circulate. They will protect, therefore, the outer sheets of the atmosphere from falling to the extremely low temperatures which sometimes have been assumed to exist there, and they may help to form the isothermal layer which balloon-observations have proved to exist at a height of about 50,000 feet."

§3. In 1907 knowledge of the state of the atmosphere above ten km was rudimentary, and it is not surprising if even so clear and cautious a thinker as Schuster misjudged the heating power of the electric currents postulated by the dynamo-theory. The advance of radio research has made it probable that the S current-system is located at a height of not less than about 60 km, so that its heating effect cannot be regarded as having any appreciable connection with the thermal equilibrium of the lower stratosphere. It is nevertheless of interest to examine the order of magnitude of the heating effect of the S current-system in the atmosphere,[2] and also that of the polar current-system associated with magnetic disturbance.

§4. Let i denote current-intensity and κ the electrical conductivity of the medium, both in electromagnetic units. In terms of these quantities the heating effect is i^2/κ ergs per cc per sec, or $i^2\ (4{\cdot}18\times10^7\kappa)$ gram-calories per sec. The rise of temperature T per sec, due to this cause alone, is

$$(\mathrm{d}T/\mathrm{d}t) = (i^2/4{\cdot}18\times10^7\ \kappa\rho C) \text{ in } {}^\circ C \text{ per sec}$$

where ρ is the density and C is the specific heat of the medium in gram-calories.

The application of this formula to the present problem is hindered by uncertainies regarding i, κ, and ρ. It is sufficient, however, to consider the order of magnitude of $(\mathrm{d}T\ \mathrm{d}t)$ at the place and time where it is likely to have its maximum value.

[1]A. Schuster, Phil. Trans. R. Soc., A, **208**, 163-204 (1907); see p. 185.

[2]In Phil. Trans. R. Soc., A, **218**, 64-66 (1919) I have already examined this question in a different way. The general conclusion there reached is the same as here, that the heating by the S current-system is unimportant; but the present discussion is based on more definite ionospheric information, and supersedes the earlier one.

§5. The electromotive forces responsible for S, on the dynamo-theory, are due to the motion of the atmosphere across the Earth's permanent magnetic field. Both the velocity and the field may probably be taken as fairly constant throughout the thickness of the layer. Hence the potential-gradient E, in the equation $E=i/\kappa$, may for our purpose be regarded as constant, and the rate of temperature-rise, which is proportional to $i^2/\kappa\rho$, or $E^2\kappa/\rho$, will be greatest where κ/ρ is greatest.

The electric conductivity in the ionosphere varies with the direction of the applied electromotive force, and its value is greatest in the direction of the permanent field, and in this direction is independent of the field; hence, in calculating the maximum value of $(\mathrm{d}T/\mathrm{d}t)$, we consider κ for this direction only. Further, the ionic contribution to this value of κ may be taken as negligible compared with the electronic contribution. The latter, when the neutral particles much outnumber the electrons (as in the E-layer, at least), may be expressed in the form

$$\kappa=(3/8\sqrt{2\pi})\ (e^2/\sqrt{kTm_e})\ (n_e/n)\ (1/\sigma_{12}{}^2)$$

assuming that the electrons collide with the other particles as if both were rigid elastic spheres, σ_{12} being the sum of the radii; here e denotes the electronic charge (in emu), m_e the electronic mass, n_e and n the number per cc of electrons and other particles respectively, k the gas-constant, and T the absolute temperature. For our purpose it is sufficient to take $\sigma_{12}=2\times10^{-8}$, $T=400°$, giving

$$\kappa=1{\cdot}36\times10^{-5}\ n_e/n$$

and

$$\kappa/\rho=1{\cdot}36\times10^{-5}\ n_e/n^2m$$

putting $\rho=nm$, where m is the mean molecular mass in the part of the ionosphere considered.

Since n^2 decreases upwards, the maximum value of κ/ρ will be found somewhat below the level of maximum n_e.

§6. The magnetic data do not directly give information about E, but give rather direct indication of the value of $\int i\,\mathrm{d}y$ integrated throughout the thickness of the layer. This integrated current is relatively large, and, at points not far from the equator it flows nearly along the direction of the magnetic field; on the local-time meridians round about 7 a. m. and 1 p. m., in summer at sunspot maximum its value may be taken as 2000 amperes per degree of longitude, or $1{\cdot}8\times10^{-5}$ emu per cm width of cross-section of the layer.

The thickness of the layer, and the height-distribution of the current within it, are not known; let h denote the thickness in km, so that the mean current-intensity $\bar{\imath}$ is $1{\cdot}8\times10^{-10}/h$. According to § 5, the value of i is likely to be greatest where κ is greatest, and since $\kappa\alpha\ n_e/n$, this will be at a level between that at which n_e is greatest, and that at which κ/ρ or n_e/n^2 is greatest. The value of i at the latter level is the one that is needed in our calculation of the maximum value of $(\mathrm{d}T/\mathrm{d}t)$, according to §5. Its ratio to $\bar{\imath}$ is unknown, but if we suppose that the value of i, at the required level, near but below the level of maximum i, is equal to $5\bar{\imath}$, we are not likely to make an underestimate. Hence we may write

$$(\mathrm{d}T/\mathrm{d}t)_{\max}=(5\times1{\cdot}8\times10^{-10}/h)^2/[4{\cdot}18\times10^7(\kappa\rho C)]$$

where the value of $\kappa\rho C$ must refer to the level at which κ/ρ is a maximum.

Though we may not know the precise nature of the gas at the level in question, there is not much uncertainty as to C, which may be taken as 0·24, the same as for ordinary air. The value of $\kappa\rho$ is $1{\cdot}36\times10^{-5}\ n_e m$, or, taking $m=5\times10^{-23}$ gm, it is $6{\cdot}8\times10^{-28}\ n_e$, fortunately independent of the air-density at the level concerned, which is rather uncertain. For n_e at the stated level near the equator at sunspot maximum we may take 10^5 or 10^6 according as the conducting layer is the E- or F-layer; to obtain an upper limiting estimate of $(\mathrm{d}T/\mathrm{d}t)$ we will take the smaller of these values of n_e, and so obtain

$$(\mathrm{d}T/\mathrm{d}t)_{\max}=1{\cdot}2\times10^{-3}/h^2$$

The order of magnitude of h, the layer-thickness in km, may be estimated as not less than 50, giving

$$(\mathrm{d}T/\mathrm{d}t)=5\times10^{-7}\text{ in °C per sec}$$

This corresponds to less than 0·°05 C per day.

Consequently one may conclude that, in the most favorable circumstances, the temperature-change due to the heating-effect of the atmospheric electric currents responsible for the solar daily magnetic variation is quite negligible compared with the temperature-changes likely to result from other causes such as the absorption of solar dissociating and ionizing radiations in the ionosphere.

§7. It is of interest to enquire also whether a much greater value of $(\mathrm{d}T/\mathrm{d}t)$ is likely to be associated with geomagnetic disturbance. The factor in $(\mathrm{d}T/\mathrm{d}t)$ which is of importance in this consideration is $i^2/\kappa\rho$; all the other factors are unlikely to be much altered in the present case.

The current-intensity i is likely to be greatest in the case of the currents that flow along the auroral zone, which during magnetic storms may attain a magnitude of the order 10^6 amperes. The cross-section of these concentrated currents is unknown, but is perhaps not likely to be less than 50 km in depth (the rather low value of h assumed in §6), nor 1° of latitude (or 110 km) in breadth. Taking these as lower limits, and supposing the total current to be 10^6 amperes, uniformly spread over this (rectangular) cross-section, we obtain $i=1{\cdot}8\times10^{-9}$ emu, or 100 times the value considered in §6.

The value of $\kappa\rho$ in the present case is difficult to estimate; this is partly because the value of n_e in the auroral zone has not been measured during a magnetic storm, at the level at which the auroral currents seem to flow, as judged from the magnetic data; at such times the air appears to become ionized much below this level, and radio echoes from the upper levels are not received owing to absorption at lower levels. Further, we are still ignorant of the origin and amount of the electromotive forces that drive the auroral current. It seems likely, however, that n_e in the current-bearing region much exceeds the value (10^5) assumed for the calculation of $(\mathrm{d}T/\mathrm{d}t)$ in §6. Another factor which must be taken into account, however, is that the auroral current flows in the direction transverse to the Earth's field, so that the value of κ to be considered is on this account probably much smaller than would be the value, for the same region, for conduction along the field (which there is nearly vertical); the ratio of reduction depends on the atmos-

pheric density at the level concerned, and since this is unknown, no definite estimate of it can be made. It appears, however, as the result of this discussion, that the $\kappa\rho$ of §6 must here be multiplied by two factors, one large (to allow for the increase in n_e) and one small (to allow for the reduced transverse conductivity). The first factor may possibly be 1000 or more; the inverse of the second factor is hardly likely to be so great; indeed a considerable proportion of the increased ionization may be near or below the E-layer, where the reduction of the transverse conductivity is negligible for the ions, and not large for the electrons. Thus $\kappa\rho$ is likely to be greater rather than less than the value used in §6. To obtain the maximum heating effect, however, let it be supposed that $\kappa\rho$ here has the same value as there.

The net result will be that the value of $(\mathrm{d}T/\mathrm{d}t)$ calculated in §6 must be multiplied by $(10^2)^2$, on account of i^2, giving $(\mathrm{d}T/\mathrm{d}t)_{\max}$, for the auroral zone, as 5×10^{-3} °C per sec. In one hour the rise of temperature on account of electromagnetic heating might thus amount to 18 °C. It should be emphasized that this estimate is very tentative.

§8. This estimated rise of temperature is quite appreciable, but under the conditions of intense ionization probably existing during magnetic storms, such electromagnetic heating seems quite likely to be a secondary effect. The ionizing agent may well produce a more direct and still greater rise of temperature, through the gradual dissipation into thermal energy of a large part of the kinetic energy of the ionizing particles. Such "primary" temperature-changes would produce convective motions of the air, which may possibly make an appreciable contribution to the electromotive forces that impel the ionospheric electric currents in the polar regions.

Summary

A calculation is made of the heating-effect in the ionosphere of the electric currents that are responsible for the solar daily magnetic variation. Contrary to a suggestion made long ago by Schuster, they are found to be quite insignificant. It seems possible, however, that the intense and concentrated electric currents that flow along the auroral zone during magnetic storms may appreciably heat the air there; but it is suggested that such heating is likely to be exceeded by more direct heating due to degradation into thermal energy of part of the kinetic energy of the incoming ionizing particles. These heating-effects would produce convective motions that may possibly make an appreciable contribution to the electromotive forces responsible for the electric current-system of polar magnetic disturbance.

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THE HEATING OF THE EARTH AND OCEANS BY INDUCED ELECTRIC CURRENTS

By S. Chapman

§1. This note is a sequel to the preceding paper, in which the heating of the ionosphere by electric currents is considered. The ionospheric currents induce secondary currents in the Earth and oceans, whose magnetic effect appreciably modifies the transient magnetic variations at the Earth's surface. The possible interest of the heating-effect of these induced currents was first drawn to my notice in 1935 by Drs. R. E. Gibson and F. E. Wright of the Geophysical Laboratory of the Carnegie Institution of Washington, who pointed out to me that if, as the analysis of magnetic records has shown, the main induced earth-currents flow at a depth of 200 km or more, any heat there generated will have much difficulty in escaping; hence a very small rate of heat-generation may be of importance. This led to my examination of the problem, with the result, perhaps to be expected, that the rate of this generation of heat is found in fact to be of too low an order of magnitude to be important, even if the heat accumulated without any escape, over the long life of the Earth, taken as 10^{10} years.

§2. The electromotive force $\oint \mathbf{E.ds}$* which impels the current-flow round any circuit in the Earth is equal to $-(\mathrm{d}N/\mathrm{d}t)$, where N is the magnetic flux through the circuit; N includes the flux due to the external currents, which (for horizontal circuits) does not vary rapidly with depth in the Earth (for the first few hundred km at least); N also includes the flux due to the induced currents themselves, which tends to neutralize or oppose the external flux. With increasing depth the total flux N in general decreases, the induced currents shielding the inner layers from the external field; but the decrease is not very rapid. The resulting decrease of the electromotive force with the depth implies a corresponding reduction of the induced current-intensity, except in so far as the electric conductivity κ *increases* with depth. This has been shown by A. T. Price and the writer to be probable, and further work by Price and Lahiri has confirmed that conclusion. But their work does not appreciably modify the estimated maximum current-intensity i found by A. T. Price and the writer as occurring during moderate magnetic storms near the surface of the conducting core of the earth. This is 3×10^{-13} emu.[1] During great magnetic storms this maximum current-intensity may rise to 3×10^{-12} emu; it endures only for a few hours, between the maximum epochs of the first and main phases of the storm. The greatest current intensity in the core due to the induced currents associated with the daily magnetic variations is likely at most to be of the order 10^{-13} emu. This intensity, though less than that of the currents induced by magnetic storms, recurs daily, whereas the other is infrequent; hence the heating due to the daily induced currents is at least comparable in importance with that of the storm-induced currents.

§3. The heat-generation per cc is equal to i^2/κ or κE^2, and as E decreases with depth, and κ increases (in the conducting "core"), the

*That is, the integration around a closed circuit; **E** denotes the electric intensity.

[1]Phil. Trans. R. Soc., A, **229**, p. 456 (1930); the omission of the minus sign before the index 13 escaped notice during proof correction, but could hardly mislead any attentive reader.

maximum generation will occur at a level somewhat below the top of the core—so far as we can speak of a "top," when there is no reason to postulate any marked discontinuity of conductivity. The probable value of κ in the region of maximum heating in the core may be taken as of the order 10^{-12} emu. Thus the heat generation will at most be of the order $(3\times10^{-12})^2/10^{-12}$ ergs per cc, or say 2×10^{-19} calorie per cc; this is actually much overestimated, because i assumes the value 3×10^{-12} only for brief and rather rare periods, except possibly near the auroral zone, where very concentrated currents flow, which will induce less concentrated but still considerable induced currents within the Earth.

In 10^{10} years, or approximately 3×10^{17} seconds, this heat would amount to six calories, sufficient to raise the temperature by 2 °C if we assume that ρC, the product of the density and the specific heat, is three. This indicates the insignificance of the heating effect of the induced currents in the core.

§4. The conductivity of the oceans is about 4×10^{-11}, 40 times as great as the value, 10^{-12} emu, assumed for the core. Since the inducing electromotive force in the oceans may be taken as the same as before, i may rise to $1{\cdot}2\times10^{-10}$ emu,[2] but the heating-effect in the upper layers of the seas will at most be about 40 times the value estimated for the core in §3, or 8×10^{-18} calorie per sec. In view of other processes of heat-interchange that go on in the seas, the effect remains insignificant, down to depths at which the induced currents become relatively small.

§5. The electromotive forces impelling the induced currents are proportional to $-(dN/dt)$, so that *ceteris paribus* they will be greatest when the external inducing field varies rapidly; for simplicity we may represent the variation in this case by a time-factor sin pt, where p is large; the induced electromotive force will then be proportional to pI, where I is the intensity of the external primary currents. In this case the electromotive force may be relatively great, and able to induce currents in a thin layer, capable of shielding the space below from the induced field. In the polar regions, where large and rapid variations of the Earth's magnetic field are most frequent, this may at times result in even greater current-intensities than 10^{-10} emu being realized, for brief periods, near the surface of the sea. Even so, the heating-effect on land will probably not exceed the maximum estimate for the core, because the conductivity of the outer layer of the Earth (even when moist) is in general distinctly less than the value (10^{-12}) assumed in §3. In the ocean, however, the heating-effect, near the surface, may possibly at times rise to ten times the estimate of §3. Nevertheless, it still seems insignificant compared with other supplies of heat available to the upper layer of the sea.

Summary

Estimates are made of the heating-effect of the electric currents induced in the Earth and in the oceans by the transient variations of the Earth's magnetic field; the effect is found to be quite insignificant.

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[2] A. T. Price points out to me that still greater values (possibly a hundred times greater) may occur in particular areas, as for example in straits affording a passage between electric current-systems in neighboring but separate oceans.

A CONNECTION BETWEEN DEEP-FOCUS EARTHQUAKES AND ANOMALIES OF TERRESTRIAL MAGNETISM AND GRAVITY

By S. W. Visser

Deep-focus earthquakes—Earthquakes with extremely deep foci occur in well-defined areas. The deepest foci, 600 km and more, are to be found in Japan, the Philippines, the Moluccas, and the Java Sea, in the Polynesian Archipelago, and in South America. Everywhere they are situated along an inclined surface, from the borders of the ocean sloping down below the continents. The slope of this surface is 30° to 40°.

Anomalies of gravity—As stated by Berlage,[1] the deep foci in the East Indian Archipelago are connected with the axis of the gravity-anomalies of Vening Meinesz.[2] Berlage "was disappointed to find no trace of deep-focus earthquakes in a rather extensive area between Celebes and Ceram, where they could certainly be expected to occur." When consulting Vening Meinesz's axis we see that in this same area the gravity-anomalies are small and that just in the neighborhood of the deepest foci they exceed −100 and even −200 milligals. We may state therefore that there exists a very close connection between these two phenomena.

Anomalies of terrestrial magnetism—Some years ago I tried to deduce the features of the normal field directly from the isomagnetic charts, avoiding Gauss's method of spherical harmonics. Although only a first approximation, the method applied revealed some remarkable features of the residual field. For particulars I must refer to the original papers.[3] For my present purpose I have reproduced a part of the map showing the residuals of the vertical component. This map contains the "zero-

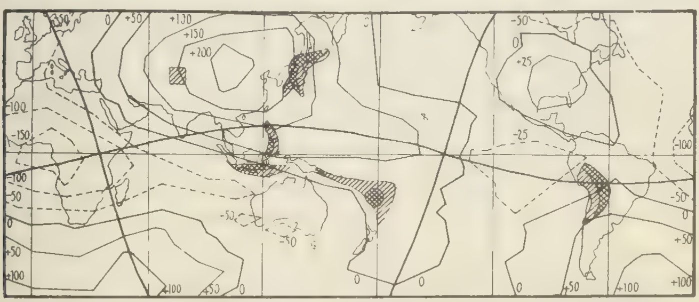


FIG. 1—ANOMALIES OF VERTICAL COMPONENT (0.001 GAUSS) AND PRINCIPAL DEEP-FOCUS REGIONS

meridian," being the great circle through the magnetic poles, and the "magnetic equator"; both circles intersect in the central part of the

[1]H. P. Berlage, A provisional catalogue of deep-focus earthquakes in the Netherlands East Indies 1918-1936, Beitr. Geophysik, **50**, 7-17 (1937).

[2]F. A. Vening Meinesz, Gravity-expeditions at sea, 1923-1932, **2** (Delft, 1934).

[3]S. W. Visser, On anomalies of terrestrial magnetism, Proc. 5th Pacific Sci. Cong., Canada, 1933, **3**, 1883-1891 (Toronto, 1934); Magnetic anomalies in the Netherlands East Indies, *ibidem*, 1893-1907

Pacific Ocean and in Central Africa. The meaning of the other curves is clear. Moreover I have plotted the areas of deepest foci, namely, Japan to New Zealand and South America.

There seems to be some relation between the two phenomena. The deep-focus areas are confined to the great regions of positive deviations of the vertical component round about the Pacific Ocean. Whereas the magnetic fields of all components show a remarkable symmetry with respect to the origin in the Pacific, the symmetry of the deep-focus areas is restricted to Japan and South America. We find no counterpart of the Australian deep-focus area in the opposite quadrant except some poorly developed deep foci of the Mexican coast and the Caribbean Sea.

If indeed the connection between anomalies of terrestrial magnetism and deep-focus earthquakes can be proved to be real, it is by no means a simple one, as appears, when we compare the fairly capricious behavior of the deep-focus areas of the southwest Pacific with the great magnetic anomaly of this same region.

The relation between the three phenomena mentioned—Vening Meinesz has found an important surplus of gravity on the oceans and a sudden decrease at the borders of the continents and has demonstrated that these deviations of isostasy cannot be situated in the thin Earth's crust, but that they must extend far into the plastic layers below. Currents must necessarily result and large current-systems must be present in the Earth's interior, downwards below the oceans, upwards below the continents. The very deep earthquakes point also to disturbances at great depths and it is worth while to state that they occur exactly at the point of the transition from the subcontinental to the suboceanic currents.

We may readily presume that magnetic disturbances must also be present. In the investigation last mentioned above[4] I found some indications suggesting a connection between the residual field in the East Indian Archipelago and the gravity-anomalies. It is not too bold to presume that the interior currents convey material with special magnetic properties from the depth and are responsible for the positive disturbances at the surface. Therefore the anomalies of gravity and terrestrial magnetism and the deep earthquakes may have a common origin, namely, the current-systems in the inner Earth.

I am aware that this suggestion is rather hypothetical, yet there are some remarkable agreements and it seems worth while to consider this matter in more detail than I have been able to do.

Leersum, Holland, August, 1937

[4]l.c. p. 1905.

AN IMPROVED INDUCTOR-COMPASS

By Ross Gunn

Abstract—A rugged type inductor-compass having a period of less than a second is described. A gravitationally oriented magnet is so arranged adjacent to an inductor turning about a fixed axis that the induced potentials, due to the existence of a vertical component of the Earth's magnetic field, are neutralized. A new type of commutator particularly suitable for very low potentials and currents is described. The compass is particularly valuable for steering aircraft or small boats.

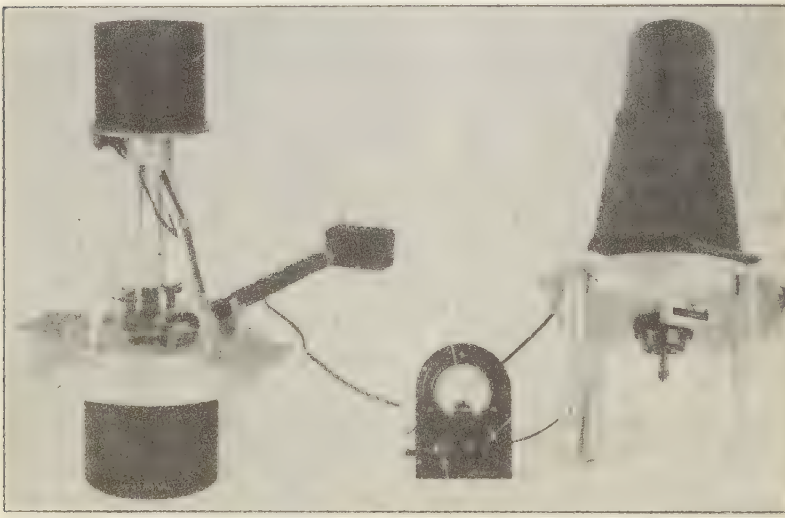
There is considerable demand for a rugged steering compass which is suitable for use on aircraft or on small power-boats. Such a compass has been developed and incorporates several novel features which are believed to be of general application and interest.

It is well known that grave practical difficulties have been encountered in the use and development of the usual types of inductor-compass and that they are unnecessarily complicated and delicate. Moreover, except for one type which was later withdrawn as impractical, the period of response of all the commercial compasses has been too great to make them valuable on small boats, aircraft, or other vehicles whose bearing may change rapidly due to waves, air-currents, etc. The present compass was designed to avoid the difficulties encountered in earlier attempts and particularly to yield a compass of very short period.

It is well known that a coil of wire rotating about a vertical axis in the Earth's magnetic field will set up an electromotive force and by suitable arrangement of a commutator and brushes, it is possible to operate a small direct current-indicator by the generated voltage. It is well known, too, that the angular displacement of the brush-structure about the commutator-axis varies the magnitude of the indicated voltage in a harmonic manner and that the position of the two points of zero voltage bear a fixed geometrical relation to the direction of the Earth's magnetic field. Therefore, such an inductor-system may be employed to indicate some definite magnetic bearing and also departures to the right or left of it. The essential parts of such a compass are: (1) A driving mechanism; (2) a system of rotating conductors or an inductor so arranged as to cut only the horizontal component of the Earth's magnetic field; (3) a synchronous rectifier to convert the induced alternating current into direct current; (4) a method for shifting the relative position of the brush-assembly with respect to the mounting and a counter to indicate its position; (5) a sensitive indicator with a constant impedance-shunt.

In the present compass an inductor is mounted to rotate on a shaft around an axis fixed relative to the airplane and is driven at reasonably constant speed by a suitably shielded motor indicated as "1" in Figure 1. The motor and its magnetic shield are mounted as far above the inductor-housing "3" as is convenient in order that stray fields may be minimized. The inductor is of the simplest type and is made out of a few hundred turns of magnet-wire wound on a soft iron or permalloy core, approximately 7 inches long and 3/16 inches in diameter. This core is mounted rigidly to the vertical drive-shaft, making sure that the windings are symmetrical with respect to the axis of spin. The driving

motor drives the inductor at the comparatively low speed of 850 revolutions per minute and thus insures a long life and reliable performance. The alternating current generated by the inductor which is encased in the housing "3" is delivered to two narrow and vertical insulated copper inserts shown as "4" in the diagram. In general the two inserts are directly opposite each other but insulated and are arranged to make contact alternately with the metallic belts "5." The metallic belts consist of endless phosphor-bronze coil springs which travel over the rotating insulated collar with copper inserts and over a solid bronze pulley like "7." Two complete sets of metallic belts and pulleys are necessary and are arranged so that one narrow copper insert is in electrical contact with one pulley during one-half a revolution and is in contact with the other pulley during the other half revolution. By reference to Figure 1 it may easily be seen that such a structure is equivalent electri-



cally to a two-segment commutator with brushes. An electrical connection is made to the center of the bronze pulley "7" in the manner shown in the photograph. The object of this particular brush-assembly is to provide actual electrical contact between the alternator element and the direct-current indicating meter without the interposition of sliding brush-contacts. This type of commutator-assembly is unusually satisfactory for the reliable commutation of small currents and performs perfectly over a period of months, even though the parts become covered with oil or other dirt. This commutator, developed after several failures, is the only one known to the author which will commutate steadily and satisfactorily the extraordinarily small voltages and current encountered in such a compass. The generated voltage in typical cases amounts to about 10 millivolts and the current to about 100 microamperes. Instability introduced into the reading of the meter by the commutator

does not exceed two microamperes. The electrical contact with the bronze pulley "7" is made by means of an axial contact "6." The bronze pulleys are driven from the main shaft by the coil-spring belts and the creeping of the latter always acts to maintain an excellent contact.

The compass is mounted rigidly to the aircraft or boat so that as the craft rolls or pitches the axis of rotation is no longer vertical and hence the inductor cuts some of the vertical component of Earth's magnetic field as well as the horizontal component. This obviously introduces a gross error into the reading of the compass and means must be provided either (*a*) to maintain the inductor always in the horizontal plane or (*b*) to introduce an electromotive force into the windings which just cancels the component of electromotive force induced by the vertical component of the Earth's magnetic field. The former method has been universally employed heretofore but the latter method offers some valuable advantages. The method of obtaining the desired result is most easily understood by reference to Figure 2. In this figure "16" is a small permanent or electromagnet mounted on gimbals "14" and so weighted as always to maintain a nearly vertical position. In adjusting the mechanism, "17" is arranged to raise and lower the compensating magnet "16" in accordance with the magnitude of the vertical component of the Earth's field. The magnet "16" is symmetrical about the axis of the rotating inductor so that when it is vertical, no electromotive force due to this magnet is introduced. However, as soon as the axis of rotation of the inductor is tipped with respect to the vertical the pendulous compensating magnet "16" makes a finite angle with the axis and the magnet has a component of magnetic moment which parallels the plane of rotation of the inductor-coil. This magnetic moment introduces an extraneous electromotive force into the inductor, which by proper adjustment, can be made just equal and opposite to the electromotive force introduced by the vertical component of the Earth's magnetic field. It has been found practicable to compensate for the Earth's vertical field component in this relatively simple manner, even though the axis of rotation is greatly deviated from the vertical.

The direct-current output from the commutator-assembly "4," "5," "6," and "7" is fed to an indicating microammeter "11" whose sensitivity may be controlled by an appropriate shunt "12" so designed that the impedance of the shunt and meter together are substantially constant. Means are provided further for rotating the commutator-assembly about the axis of rotation by means of a worm "8" which extends through suitable flexible shafting to a small handle contained in a box "9," which, in turn, is geared to a small counter in such a way that a complete revolution of the commutator-assembly records 360°.

The operation of the device is as follows: The compass is installed in some suitable place on the aircraft, usually in the tail. The small control-panel which includes the microammeter, on-and-off switch, and sensitivity-control, together with the control-crank "9" and counter "10," is installed in a place accessible to the pilot. The ship is placed in flying aspect on a north magnetic heading, say, the counter which indicates the magnetic azimuth of the course is set to zero and the worm or compass adjusted so that the meter "11" reads zero. If the ship is unsymmetrically magnetized or if the compass is located in a bad place, these stray magnetic fields may need compensation by well-known methods.

Now if the tail of the airplane is raised and lowered, an adjustment of the position of the magnet "16" will be found where no change in the meter-reading "11" takes place. During this operation it is essential that friction in the universal mounting "14" does not prevent the magnet from assuming a truly vertical position. A certain amount of friction in this mounting is necessary to prevent free oscillation of the compensator-assembly "14," "15," and "16" but the friction should not be so great that the magnet "16" will not quickly seek the vertical under the stimulation of the normal vibrations present on the ship. Alternately the ship may be taken in the air and "17" adjusted until, with the ship on a steady course under conditions of roll and pitch, the indicator-needle remains essentially steady. An airplane flying many hundreds of miles north or south will find it necessary to readjust the clearance of the magnet by turning "17." This adjustment may be abolished by making "16" into an electromagnet[1] and it becomes only necessary for the pilot to turn a small knob until the needle is steadiest under rough air-conditions.

To use the compass the driving motor is turned on, the magnetic azimuth of the desired course is set on the counter "10" by turning the handle "9" and the bearing of the ship changed until the meter-reading is zero. As the ship turns off of the selected course the meter reads to the right or left by an amount which is proportional to the deviation from the chosen course. All that is necessary for the pilot to do thereafter is to keep the needle in the center of the meter. The sensitivity selected as most suitable for use in aircraft approximates one millimeter per degree. A sensitivity-control is employed so that a pilot may reduce the sensitivity during exceedingly rough weather.

The outstanding advantage of this type of compass is its simplicity and its extraordinary short period which in most cases does not exceed one-half second. Thus the roll or pitch of a quickly responsive boat or airplane cannot introduce cumulative error into the reading of the meter, and its instantaneous reading closely approximates the true bearing. For this reason, this type of inductor-compass is extraordinarily suitable for blind flying and indeed has been used for this service. Reliability of operation has been achieved by adopting rigid structures for all rotating parts, by the employment of moving electrical contacts of an unusual nature which can best be described as rolling and by employing a slow-speed inductor. In spite of this, the weight of the device is not excessive; the instrument shown weighs 12 pounds, although similar compasses weighing as little as seven have actually been manufactured. The compass has been thoroughly tested and used on small boats and on airplanes.

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[1]For example, see Gunn's United States Patent No. 2,054,318.

THE DETERMINATION OF THE MAGNETIC INCLINATION WITH AN EARTH-INDUCTOR

By J. Egedal

Abstract—The method used at the Rude Skov Observatory to obtain more accurate determinations of the magnetic inclination is described, and the need in general of accurat determinations of the inclination is emphasized

Even if other electrical methods than that of the earth-inductor will be used at some of the magnetic observatories for the determination of the vertical force (Z), no doubt the earth-inductor for many years will be used for that purpose at many observatories in all parts of the world. Therefore it is of importance that the measurements by means of the earth-inductor be improved and that most efficient use of the instrument be obtained.

In comparing the monthly means of Z obtained at Rude Skov for the year 1934 with monthly means for the same year of other magnetic observatories in the northwestern part of Europe it was evident that the annual variation for some of the observatories differed considerably from the mean annual variation of all the observatories considered (see Fig. 1). The disagreement found has led to the same conclusion as

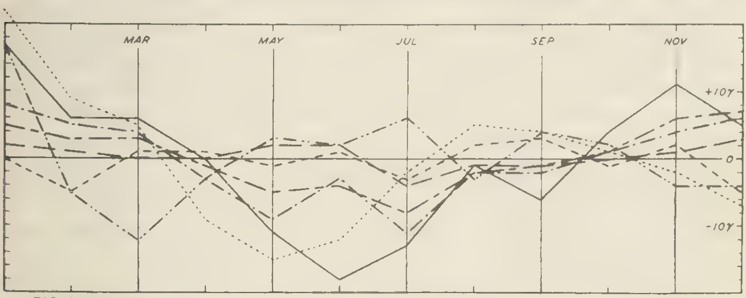

FIG. 1—ANNUAL VARIATION OF VERTICAL INTENSITY, Z, FOR 1934, AT OBSERVATORIES IN NORTHWESTERN EUROPE (SECULAR VARIATION ELIMINATED)

that of Ad. Schmidt[1] by similar investigations, namely: "Die Betrachtung der hier für die verschiedenen Observatorien mitgeteilten Zahlen löst besonders bei der vertikalen Komponente an vielen Stellen erhebliche Zweifel an ihrer Zuverlässigkeit aus."

In determining the vertical force by means of an earth-inductor, using the relation $Z=H \tan I$, the errors ($\triangle Z$) of Z can be expressed by the formula

$$\triangle Z=\tan I\triangle H+H \sec^2 I\triangle I$$

Inspection of monthly means of Z often shows that a certain monthly mean differs considerably from the consecutive means. If this difference is due to errors in H and I it may be easily seen by referring to the formula whether the difference originates chiefly from errors in H (the first member of the formula) or from errors in I (the second member).

An examination of the above-mentioned disagreement between annual variations of Z for observatories in the northwestern part of Europe and of suspicious-looking monthly means of Z obtained at magnetic observatories in all parts of the world has shown that errors of Z originate as well from errors in H as in I.

[1]Arch. Erdmag., Heft 3, p. 13 (1918).

Here the question of reducing errors in I will be considered. To obtain accurate determinations of the inclination with an earth-inductor a method securing control of the adjustment and working conditions of the earth-inductor has been used at the Rude Skov Observatory for a few years. By this method the observer may also determine the relative accuracy of his measurement. The method has proved very useful and possibly it might be of interest to observers at other magnetic observatories.

Accurate determinations of the inclination with an earth-inductor can only be made when the inductor is in complete adjustment. Thus all magnetic parts of the inductor must be removed and replaced by non-magnetic parts; the meridian-setting must be correct; the insulating part of the commutator must be placed so that the brushes touch the middle of it when the normal of the plane of the coil lies in the magnetic meridian; the conducting part of the commutator and the brushes must be clean; during the rotation of the coil the position of its axis must not change more than $\pm 0'.1$. Many other things must be in proper order as will be seen in directions for magnetic measurements.[2]

To obtain a correct meridian-setting it is necessary to determine the correction for the compass for meridian-setting. This may be determined directly. At Rude Skov the following method was used: After the meridian-setting was made a mirror was fixed to the coil so that its normal was nearly parallel to the axis of the coil and so that upon rotating the coil the mirror could be observed in a telescope placed two meters from the earth-inductor. The direction of the axis was determined from two positions of the coil 180° apart, and the angle between the direction of the axis and the magnetic north-south direction, as found by means of a magnet, was determined. Then the correction of the compass was easily found.

If there are no thermal electromotive forces during observation, which was the case in Rude Skov, the correction may be found in the following manner: The axis is placed out of the supposed magnetic meridian (say 30′ on the horizontal circle) and settings for positive and negative rotation are made; the axis is then placed 30′ on the opposite side of the supposed meridian and similar settings are made. The difference between readings (reduced to the same H and Z) for positive rotation and negative rotation is computed in the two cases and by simple interpolation the reading on the horizontal circle for which the difference is zero is determined, and this reading corresponds to the meridian. Then the correction of the compass is easily found. The correction found in Rude Skov for the compass was $-12'$. In the above considerations it has been assumed that the horizontal axis of the earth-inductor is perpendicular to the axis of the coil.

If the meridian-setting is correct, and if the earth-inductor is in all other respects in complete working order, then theoretically only observational errors should affect the settings in the dip line ("axis inclined") and consequently a single setting can be considered as a determination of the absolute value of the inclination.

Making settings for circle east and circle west, for commutator up and commutator down, and for positive rotation and negative rotation, results in eight settings. If one (or more) of these, after reduction to the

[2]See O. Venske, Göttingen, Nachr. Ges. Wiss., 219-229 (1909); also N. E. Dorsey, Terr. Mag., **18**, 1-38 (1913).

same H and the same Z, leads to a value of the inclination differing more than 0′.5 from the mean of all eight values, then possibly something is not in order and the observer must determine the trouble, adjust for its correction, and make a new measurement.

Observations of magnetic inclination

Observatory: Rude Skov — Date: August 3, 1937
Earth-inductor: Edelmann — Observer: J. Egedal

Vertical circle east—Magnetic meridian reads 244°.70

Axis vertical

Commutator	Coil	Time		A			B			Mean	
		h	m	°	′	d	°	′	d	°	′
Down	N	Begin		270	00	1.1	90	00	1.0	180	02.1
	S					1.0			0.9		01.9
Up	N					1.15			0.85		02.0
	S					1.15			0.85		02.0
Down	N	End				1.05			1.0		02.05
	S					1.05			0.95		02.0
Up	N					1.1			0.85		01.95
	S					1.15			0.9		02.05
							Mean			180	02.01

Axis inclined

Commutator	Coil	h	m	°	′	d	°	′	d	H (d)	Temp. (°)	Z (d)
Down	+	14	01	290	20	2.6	110	20	2.35	606.3	19.0	303.7
	−		04.5			2.7			2.55	6.25		4.0
Up	+		08			2.9			2.1	6.3		4.3
	−		09.5			2.9			2.1	6.0	19.0	4.2

Vertical circle west—Magnetic meridian reads 64°.72

Axis vertical

Commutator	Coil	Time		°	′	d	°	′	d	°	′
Down	N	Begin		270	00	0.65	90	00	0.4	180	01.05
	S					0.8			0.6		01.4
Up	N					0.8			0.45		01.25
	S					0.8			0.45		01.25
Down	N	End				0.6			0.3		00.9
	S					0.8			0.55		01.35
Up	N					0.85			0.45		01.30
	S					0.8			0.4		01.20
							Mean			180	01.21

Axis inclined

Commutator	Coil	h	m	°	′	d	°	′	d	H (d)	Temp. (°)	Z (d)
Down	+	14	35	249	20	8.75	69	20	8.9	609.1	19.0	306.9
	−		37.25			8.8			8.95	09.5		7.1
Up	+		40.25			8.65			8.95	10.2		7.65
	−		44			8.75			9.0	09.5	19.1	7.55

From the eight reduced values of the inclination the observer will be able to determine the relative accuracy of his measurement, for instance, by computing the standard deviation of the mean of the eight values.

To illustrate the procedure an observation of the inclination at Rude Skov, August 3, 1937, is given below in a form similar to that used by D. L. Hazard in "Directions for magnetic measurements" (third edition, p. 79, 1930).

The scale-values for readings of the variometers above are: For H, 3.8 gamma mm; for Z, 3.4 gamma mm. The temperature-coefficients are: For H, -1.1 gamma degree; for Z, zero. The observed readings have been reduced to the value of H corresponding to 606.3 ($t=19°.0$), and to the value of Z corresponding to 303.7.

The reduction is made according to the formula

$$\triangle I' = 3438\ (\cos^2 I/H)\triangle Z - 3438\ (Z\cos^2 I/H^2)\triangle H$$

where Z and H are the departures from the values of Z and H to which the readings are reduced.

Computation

Face	Vertical circle Mean °	′	Reduction H ′	Reduction Z ′	Vertical Circle corrected °	′	Resulting I °	′
East	200	24.95	0.00	0.00	200	24.95	69	37.06
		25.25	+0.01	+0.02		25.28		36.73
		25.0	0.00	+0.05		25.05		36.96
		25.0	+0.08	+0.04		25.12		36.89
West	159	37.65	+0.73	−0.26	159	38.12		36.91
		37.75	+0.83	−0.27		38.31		37.09
		37.6	+1.01	−0.32		38.29		37.08
		37.75	+0.83	−0.31		38.27		37.06
					Mean		69	36.97 ± 0′.044

The relative accuracy obtained at Rude Skov corresponds to a standard deviation for I of 0′.05 to 0′.10, which is the same accuracy as that obtained by O. Venske[3] and by H. Wild, the latter of whom in the year 1895 designed the earth-inductor of the type considered. Thus no great progress has taken place as regards the accuracy of the measurements with the earth-inductor, but modern variometers with almost constant base-line values may be of importance for the correction of these measurements.

Even if the observer in using the above method should be able to control his measurement of the inclination and to obtain values differing very little from the true value, yet comparisons between earth inductors are important; they furnish confirmation that the earth-inductors compared give practically the same value. Thus, in comparing two earth-inductors repaired here the following corrections to the Rude Skov earth-inductor were found: $+0'.02 \pm 0'.04$ and $-0'.04 \pm 0'.035$. The corrections simply indicate that no difference could be stated.

In conclusion I thank Professor O. Venske of Potsdam for his kind advice and valuable help in connection with the questions discussed in the present article.

Copenhagen, Denmark

[3] Berlin, Veröff. Met. Inst., Nr. 327, 91-96 (1925).

ATMOSPHERIC ELECTRICITY AT THE COLLEGE-FAIRBANKS POLAR YEAR STATION

By K. L. Sherman

Abstract—The atmospheric-electric program at College, Alaska, during the second International Polar Year extended from October 1, 1932, to August 31, 1933. (1) Continuous registration was made of air-potential with a recording quadrant-electrometer and a radioactive collector on a horizontal rod at the variation-observatory and during most of the time also with a recording bifilar-electrometer with radioactive collectors exposed by the stretched-wire method for control at a standardization-station. (2) Continuous registration was made of air-conductivity due to both positive and negative ions, using semi-portable apparatus in which the deflection is nearly proportional to the conductivity; in this apparatus the charge collected by the Gerdien condenser flows to earth through a resistance of about one electrostatic unit and the resulting voltage-drop through this unit is recorded by a single-fiber electrometer. (3) Determinations of the number of positive and negative small ions, usually made once each day, using a modified Ebert ion-counter. (4) Determinations of the number of condensation-nuclei, once daily from late in March through August, using an Aitken counter; during the cold weather the counter did not function satisfactorily.

These data conform with those obtained in lower latitudes at stations on land that are relatively free from variable sources of pollution. The average gradient for all complete days for the eleven-month period is 104 volts per meter with a maximum in January and a minimum in August. Harmonic analyses of the hourly values show that a 24-hour component exists in gradient, in substantial agreement with Mauchly's findings. All complete days of positive and negative conductivity yield average values of 179 and 131×10^{-6} electrostatic unit, respectively. The variations are approximately the inverse of those in the gradient although their product—the electrical conduction current—shows regular daily and seasonal variations. The average number of positive small ions by months varied from a minimum of 620 per cc in July to a maximum of 980 in November. The number of negative small ions varied from 520 per cc in July to 660 in November and February. From the ion-count and the corresponding values of conductivity a mean value of 1.56 cm^2 $volt^{-1}$ sec^{-1} for the mobility of both the positive and negative small ions was found, although different mobility-groups are indicated by frequency-curves. The average of 112 determinations of nuclei is 3760 per cc.

The electrode-effect appears to be quite important at this station. The ratio of positive to negative conductivity varies directly as the gradient, both in long-period and short-period changes. This and other features of the results are explicable on the basis of conditions as they would exist in quiet air. At times turbulence is effective in complicating the relations between the elements and so for a complete explanation of these results the effect of mixing must be considered in addition to conditions as they would exist in quiet air.

Measurements of elements of the Earth's magnetic and electric fields were made at the College-Fairbanks Polar Year Station during the International Polar Year of 1932-33. These measurements were begun in September, 1932, at College, Alaska, by the United States Coast and Geodetic Survey and the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, D. C., in cooperation with the University of Alaska (formerly the Alaska Agricultural College and School of Mines). Some of the results obtained have already been published[1, 2, 3]. It is the purpose of this report to give more details of the program in atmospheric-electricity, which included continuous registrations of the potential of the air at a variation-observatory, of the potential-gradient at a field-station, and of both positive and negative conductivity, as well as daily eye-observations of the number of small ions.

[1]W. J. Rooney and K. L. Sherman, Terr. Mag., 39, 187-199 (1934).
[2]K. L. Sherman, Trans. Amer. Geophys. Union 15th Annual Meeting 141-142 (1934).
[3]W. J. Rooney, Terr. Mag., 39, 103-109 (1934).

of the number of Aitken nuclei, and of pertinent meteorological observations. Data were obtained and have been evaluated for eleven complete months—October, 1932, to August, 1933.

Description of station—The station was on the grounds of the College about three miles west and north of Fairbanks, Alaska, approximately 180 meters above sea-level, in latitude 64°.9 north and longitude 147°.8 west. Figure 1 shows the station shortly after construction and the

relative locations of the observatory and buildings of the University, all on a hill about 25 meters above the adjacent level country. The building which housed the atmospheric-electric apparatus is in the center foreground; the tubes projecting from the roof supplied the sample of air to the apparatus. In the right foreground are the buildings for the magnetic variation and absolute observations. The ground immediately in front of the observatory was under cultivation—a crop of oats was grown during the summer of 1933. In other directions the land was uncultivated but was cleared of most tall vegetation. The gentle

rise continued to the rear through an area of more dense and taller vegetation—an area used for grazing.

The standardization-station where the potential-gradient was recorded to determine the factor to convert the potential of the air as recorded at the terrestrial-electric observatory to units of volts per meter, was about one mile east on lower and level ground. Some of the terrain near this location, the small building which housed the equipment, and some details of the installation are shown by Figure 2. The area was generally swampy with a deposit of sandy loam on which the station was

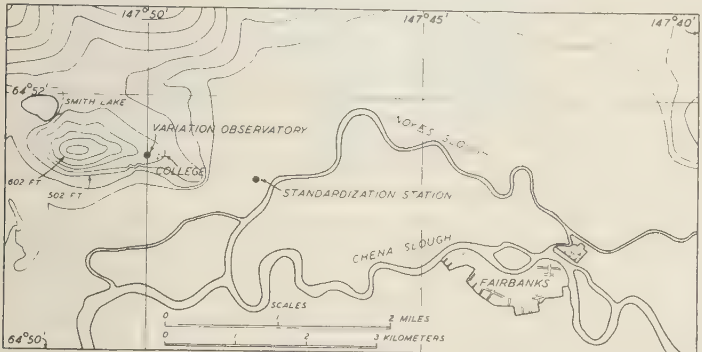

FIG. 3—COLLEGE-FAIRBANKS AREA SHOWING POSITIONS OF VARIATION-OBSERVATORY AND POTENTIAL-GRADIENT STANDARDIZATION-STATION, 1932-33

built. Vegetation that would have affected appreciably the field at the collector, as judged by the dimensions of the object and its distance away, was cleared from the site.

The positions of the variation-observatory and of the potential-gradient standardization-station relative to College and Fairbanks are shown in Figure 3. The topography of the area is represented by the contour-lines to show 25-foot intervals.

Potential-gradient apparatus—A Benndorf recording-electrometer, mounted on a concrete pier, recorded the potential of the air at the terrestrial-electric observatory. The collector, mounted at the outer end of a steel rod, was a brass disc coated with an ionium compound. The collector-rod was supported by a wooden box which passed through the front wall of the building. The rod passed centrally through two, circular, amber insulators 4.5 cm in diameter and two cm thick, spaced 35 cm apart in the mounting box. The air in contact with the surfaces of the insulators had the moisture removed from it by a desiccant kept in glass jars within the box. The box, lined with copper sheet, was designed so it could be quickly opened to renew the desiccant and readily removed to examine and care for the insulated system. A stiff rod connected the inner end of the collector-rod and the needle-system of the electrometer and so no insulators except those mentioned above and those of the electrometer were required. This wire ran concentrically through a metal tube 20 cm long and two cm in diameter, which shielded the wire electrically and protected it mechanically. Thermostatically controlled electric heater-units maintained the temperature in the insulated build-

ing above the freezing-point of the sulphuric-acid solution used within the electrometer-house. This acid served the threefold purpose of removing moisture from the air, of providing a damping medium for the electrometer-needle, and of making a flexible connection to the moving system. The desired sensitivity of ten volts per mm was obtained with a potential of some 180 volts from four dry-cell batteries applied between the quadrants of the electrometer. The central terminal of the batteries was connected to the case of the instrument and to earth. An electromagnet was installed in the electrometer which when energized connected the collecting-system to the insulated core of the electromagnet. The clock which controlled the time-marks for the conductivity-apparatus once an hour also closed the circuit which energized this electromagnet. At such times the core, and so the collecting-system, was connected to earth-potential giving a base-line and time-control marks on the record in addition to those put on by the device incorporated in the instrument by the manufacturers. A manually operated switch also controlled the electromagnet so that any desired potential could be applied to the collecting-system for purposes of calibration and tests of insulation-resistance.

The support for the collector-rod was designed so the rod could be easily removed when it was desired to test the insulation-resistance. More satisfactory tests were obtained by having the joint close to the mounting than would have resulted if instead the collector had been removed from the rod since changes in deflection caused by induction on the insulated system from the varying field of the Earth were greatly reduced. The collector was placed as far from the front of the building and from the ground as practicable in order to secure desirable deflections on the electrometer and so that the recorded values would be less affected by the varying distributions of snow shifting the equipotential surfaces near the collector. The collector was situated about one meter from the front of the building and two meters from the ground. This resulted in a reduction-factor to reduce the recorded potentials to volts per meter over a level surface, slightly greater than unity.

A Gunther and Tegetmeyer recording bifilar-electrometer was used in connection with the Simpson stretched-wire arrangement to register the potential-gradient at the field-station. Certain mechanical details of the recorder were modified to adapt it to the installation. A wire 60 feet (18 meters) long was stretched one meter above the surface of the ground between two sulphur strain-insulators designed for that purpose. One of the insulators was fastened to the side of the building and the other to a post set in the ground. Brass discs coated with an ionium compound were attached to the wire somewhat nearer the post than the building to serve as a collector. Two discs were used, back to back, in order that the potential assumed by the wire would be nearly that of the air at the height of the wire. A cylindrical, amber insulator 7.2 cm in diameter and 2.5 cm in thickness was held in a metal support which was mounted in the side of the building just above the end of the stretched wire (see Fig. 2). The short lead from the stretched wire to the electrometer passed through the center of this insulator. Two 45-volt batteries maintained the inner case of the electrometer at a potential of −90 volts relative to the outer case for the purpose of deflecting the

fibers to the sensitive and linear portion of their range during registration of normal gradients and of permitting distinction between positive and negative gradients. The electrometer-sensitivity was such that a potential-difference of 25 volts caused the image of each fiber to deflect one mm on the record.

Air-conductivity apparatus—Two complete units recorded simultaneously and continuously the air-conductivity due to both positive and negative ions. These units were of the steady-deflection type, designed and built at the Department of Terrestrial Magnetism for semi-portable use. Each was similar, except in a few details, to a single unit installed on the *Carnegie* for a part of its last cruise. Apparatus designed for permanent installations at observatories[4] and the unit used on the *Carnegie*[5] have been briefly described. In view of the brevity of existing descriptions and of their inaccessibility to many readers it is considered advisable to give a somewhat more detailed description here.

Each unit may be considered to consist of four functionally different parts as follows: (1) The Gerdien condenser—a cylindrical, electrical condenser—in which electricity is dispersed from the central element of the condenser at a rate proportional to the electrical conductivity of the air drawn through the condenser; (2) a device to indicate the rate of dispersion which consists of a single-fiber electrometer arranged to measure the voltage-drop caused by the current flowing through the Bronson cell, the resistance of which is of the order of one electrostatic unit; (3) a clock-driven drum carrying photographic paper for recording the deflections of the electrometer; (4) auxiliary equipment for calibrating the units consisting of a source of voltage, the use of which gives the voltage-sensitivity of the electrometer, and of a source of current of known and variable magnitude which when substituted for the current which flows while recording gives comparative deflections.

The assembly is shown in Figures 4 and 5. Many details which make for ease and simplicity of operation have been omitted from the diagram

[4]W. F. G. Swann, Carnegie Inst., Year Book, No. 16, 279-281 (1917).

[5]G. R. Wait, O. H. Gish, and C. Huff, Carnegie Inst., Year Book, No. 28, 275 (1929).

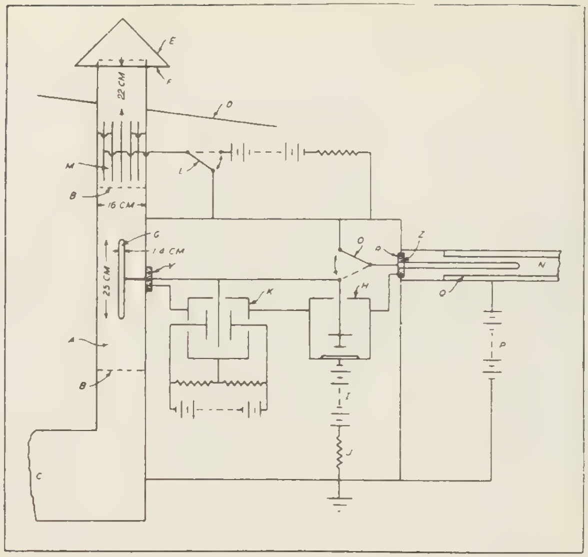

FIG. 5—SCHEMATIC DIAGRAM OF THE AIR-CONDUCTIVITY APPARATUS, COLLEGE-FAIRBANKS (ALASKA) POLAR-YEAR STATION, 1932-33

to facilitate and to clarify description. The Gerdien condenser (*A*) whose important dimensions are indicated in the diagram was mounted in a vertical position. The outer element of the condenser was constructed from a brass cylinder while the inner element (*G*) was of aluminum tubing with rounded plugs in the ends. Two circular screens (*B*) were fitted into the outer cylinder. These screens—woven five meshes to the centimeter from wire 0.3 mm in diameter— besides fixing the length of the electrical condenser, prevented the entrance of insects, lint, and other undesirable materials. The outer cylinder extended below the condenser where it terminated in a wooden duct (*C*) common to both units. At the center of this duct a fan, driven by an electric motor, drew air downward through the tubes and discharged it through an outlet in the duct which projected from the front of the building. The upper end of the outer cylinder projected above the roof of the building (*D*) and was covered with a conical hood (*E*) to prevent the entrance of snow and rain. The base of the cone was 3.5 cm below the top of the tube. Between the base of the cone and the cylinder another wire screen (*F*), of the same material as that described above, was mounted to further prevent the entrance of undesirable foreign material.

The central cylinder (*G*) was maintained at a suitable potential by batteries (*I*) connected in series with the high resistance (*H*) and the battery protective resistance (*J*), between the central cylinder (*G*) and earth. The potential of the batteries *I* was approximately 45 volts for the unit recording positive conductivity throughout. For the unit recording negative conductivity a potential of 45 volts was used until February, 1933; it was then increased to 90 volts. A single-fiber

electrometer (K) recorded the voltage-drop through the resistance (H) due to the flow of current. During operation this current is given by $4\pi\gamma\lambda V$ where γ is the measured capacitance of the portion of the insulated system exposed to the air-flow, λ is the unipolar conductivity, and V is the potential of the central cylinder. The value of γ was taken to be 6.14 cm—that found from an accurate determination of this factor on another unit whose essential dimensions were in such agreement with those of the present units that this value would apply within five per cent to these as well. The potential V is equal to that of the batteries I corrected for the voltage-drop across the resistors H and J. Although these corrections are often insignificant, they must be considered.

Once each hour a point for the base-line was recorded. To obtain this point the contactor L was thrown for four minutes from its normal earthed position to a point at a potential of about 270 volts. Then the condenser M removed from the air-stream all ions which had a mobility greater than 0.2 cm^2 $volt^{-1}$ sec^{-1}. This method of obtaining the reference-point is superior to that of shutting off the air-flow in that it eliminates error that would be caused by contributions to the current from deposits of radioactive materials on the walls of the dispersing condenser or other corresponding sources of conductance, since such currents would with this method be present during the time of hourly zero as well as during time of normal registration.

A simple potential-divider, designed for use with a voltmeter to indicate the applied potentials, was used for the voltage-calibration of the electrometer. A sensitivity of 12-mm deflection per volt was found to be satisfactory. The determination of sensitivity is not required for reduction of the data. However it is helpful to determine how the electrometer is functioning, what part of the changes which occur in the overall sensitivity of the unit between calibrations is attributable to variations in the resistance of the Bronson cell, and what part to changes in electrometer-sensitivity.

The current-sensitivity of the apparatus was determined by substituting a current of known value for the normal registration-current. The current due to conduction in the Gerdien condenser was first eliminated by reducing the potential at I to zero. Then with the arm O in contact with the insulated system a steady current was generated using the variable condenser N with the potential P applied between it and earth. The change in capacitance of N for unit-change in position of the traveling cylinder Q was computed from the dimensions of the condenser. Comparative calibrations made by an independent method checked this result. The calibration-current was computed as the product of this constant into the observed rate of travel of Q and the potential P in volts. Direct experiments had shown that end-effects were negligible throughout the range in which the condenser was designed to operate. To obtain a uniform rate of change the movable element was driven by a direct-current motor which was controlled by a governor. The rate of travel of Q was obtained from simultaneous readings of a watch and of a revolution-counter attached to the drive-shaft.

To insure adequate insulation, all insulators which supported parts of the insulated system were made of amber and drying material was used to remove moisture from the air in contact with their surfaces. Phosphorous pentoxide was used as the desiccant for the outer surface

of the supporting insulator for the central cylinder. All other surfaces were exposed to the air inside the metal box which housed the apparatus. This box was sealed with gaskets and contained jars filled with desiccating material. The insulated metal collar (Y) holding the supporting insulator for the central cylinder was connected to the base of the electrometer and so served as a guard-ring. Thus a much lower value of insulation-resistance could be tolerated than if this support had been at earth-potential. With this device the difference of potential across all insulators supporting the collecting-system was only that recorded by the electrometer. Low values of insulation-resistance affect the accuracy slightly in this method, provided that its variations during registrations are small and that calibrations are spaced so as to give the average conditions. It should be noted that conditions of insulation are the same while calibrating as while recording except for the extra insulator Z supporting the central cylinder of the calibrating-condenser. Provision was made for measuring the resistance of this insulator to determine the loss of charge across its surface during calibration. This was done by connecting the insulator-support and guard-ring R to the outer cylinder of the calibrating-condenser instead of to the base of the electrometer as during calibration. The current was then recorded which flowed with the cylinder Q stationary and a potential applied at P. No difficulty was found in keeping the error in the calibration-current due to the loss of charge over this insulator to much less than one per cent.

The path of light from the electrometer to the clock-driven drums (S), which carried the photographic paper, was enclosed in light-tight boxes (T) so that it was unnecessary to darken the room when recording. Each drum was in a case equipped with a shutter and the whole case could be readily removed to a dark-room to renew the photographic paper.

Ionic-content apparatus—The apparatus used to determine the small-ion content of the air was constructed in the instrument-shop of the Department of Terrestrial Magnetism. It was similar in design to Swann's modification of the Ebert counter and embodied a standard, single-fiber electrometer, anemometer, and air-turbine. The latter drew approximately 1000 cc of air through the tube per second. A potential of 23 volts was applied between the intermediate and outer cylinders and although the conduction-factor[6]—the value of γ in the expression $4\pi\gamma\lambda$ for the conductance—is not known exactly, if it is assumed to be ten cm, all ions which had a mobility greater than 0.35 cm^2 volt^{-1} sec^{-1} were collected. Three 45-volt dry-cell batteries were used to supply the field between the induction-plates of the electrometer. The tension on the fiber and the distance between plates were adjusted so that a voltage-sensitivity of about 30 divisions per volt was obtained. The capacitance of the apparatus was determined experimentally and was found to be 35.9 cm. A cylindrical duct, eight inches in diameter, of galvanized iron passed through the roof of the building to the outside air. Its top was covered with a coned hood to prevent the entrance of snow and rain. A small door, hinged to the ceiling of the building, covered this opening except when the aparatus was in position for an observation.

[6]O. H. Gish, Terr. Mag., 38, 257-259 (1933).

Operation—The main observatory was visited several times each day to check the operation of the apparatus and to make the necessary control-observations. A voltage-calibration of the Benndorf electrometer and a test to determine the resistance between earth and the insulated system were made daily. Four potentials, approximately 0, 80, 160, and 240 volts, applied to the insulated system for two minutes, constituted a calibration. The voltages as applied were read from a voltmeter connected in parallel with the electrometer during calibration. The test of insulation was made by removing the collector-arm from its mounting, charging the insulated system to a potential of 240 volts, and allowing the change of potential to be recorded for about seven minutes. After the test was completed the rod-mounting was examined for possible sources of trouble and the parts were brushed to remove any foreign material present. Some difficulty was experienced during the coldest period because of frost which formed across the gap between the collector-rod and its mounting, doubtless enhanced by the escape of air from the warm interior of the building.

The battery-potentials of the conductivity-apparatus were measured once a day to ascertain if they were being properly applied and to obtain their absolute value. These potentials included that maintaining the potential of the collecting-cylinder, that supplying the field between the induction-plates of the electrometer, and that applied to the auxiliary condenser once an hour. When possible the central cylinder was removed and brushed each day principally to remove spider-webs which might have bridged the gap from the inner to the outer cylinder. During the winter, when the tubes were wrapped with felt to decrease the loss of heat from the building, the tubes and felt became coated with frost and ice making it impossible to follow this procedure daily. Fortunately this condition coincided with the season which was not conducive to trouble from spiders. The apparatus was calibrated about once each week. In current-calibration four points on the curve of current versus deflection were obtained by applying different potentials, including zero, to the calibrating-condenser. Four points, including the one corresponding to zero-voltage, were recorded also to determine the curve of voltage versus deflection for the electrometer. The velocity of the air-stream through the tubes was measured occasionally by a small anemometer. Normally this was approximately nine times as great as computation indicated was required to insure that the current be proportional to the applied potential.

Observations were made once each day to determine the number of small ions of both signs present in the air. A single determination consisted of determining the time required for the collecting-system to charge by a definite amount, as indicated by the movement of the fiber, from its initial deflection to an equal deflection of opposite sign. Usually at least five readings were taken alternately for ions of each sign. Before and after a set of readings an insulation-test and voltage-calibration were obtained. The latter consisted of noting the voltages corresponding to the positive and negative deflections used during the observations. The insulation-test was made by noting the rate of change in deflection of the fiber starting with zero-charge on the insulated system. The method of observation eliminated the effect of loss of charge from the insulated system directly to the earthed case of the instrument since

during the time of one-half of the observations the loss would add to and during the other half subtract from the conduction-current in the air-stream. The test was necessary, however, to determine if leak existed between the central cylinder and the charged, intermediate cylinder.

The potential-gradient field-station was visited once each day. Calibrations of the electrometer were carried out in the same manner as for the Benndorf recorder. The sulphur-insulators were removed from the stretched-wire system for making a test of their insulation. For this test they were placed in a metal container and each of their surfaces were connected in parallel with the electrometer. The rate of discharge was obtained as outlined for the Benndorf recorder. The approximate capacitance of the set-up had been determined so that it was possible to determine the average resistance with sufficient accuracy. This method of testing the insulation-resistance was considered superior to one in which the collectors are removed from the wire, the rest of the apparatus remaining in place, in that the effect of induction due to changes of the field of the Earth was obviated and dissipation of charge from the stretched wire was eliminated.

Table 1—*Mean hourly values of atmospheric potential-gradient in volts per meter, for all complet days, October 1932 to August 1933, College-Fairbanks Polar Year Station*

(Tabular values are averages of 60-minute means centering on the half-hour)

150° west M.M.T. hours	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Means: 11 months	Means: Winter[a]	Means: Equinox[b]
0– 1	75	107	108	114	101	105	88	83	85	91	71	93	108	89
1– 2	81	112	120	114	100	107	99	81	85	94	77	98	112	96
2– 3	85	120	119	128	109	112	100	90	77	104	80	102	119	99
3– 4	89	111	117	131	109	117	116	98	85	103	75	105	117	107
4– 5	101	106	111	128	108	117	110	108	104	112	74	107	113	109
5– 6	95	108	111	132	112	118	121	110	102	109	81	109	116	111
6– 7	97	106	114	129	117	123	120	113	104	94	102	111	116	113
7– 8	105	115	118	145	123	134	140	111	98	109	118	120	125	126
8– 9	120	146	142	160	166	150	135	108	106	126	134	136	154	135
9–10	117	152	150	151	170	153	152	100	109	128	125	137	156	141
10–11	116	143	147	155	169	140	148	101	111	121	111	133	154	135
11–12	108	136	127	146	144	128	132	103	95	112	97	121	138	123
12–13	96	110	124	146	125	104	124	96	85	101	91	109	126	108
13–14	83	104	111	139	118	95	112	84	89	93	88	101	118	97
14–15	80	95	106	117	107	85	94	68	89	81	84	91	106	86
15–16	81	86	103	112	106	92	91	69	90	84	80	90	102	88
16–17	85	87	98	126	108	79	87	68	96	91	75	91	105	84
17–18	86	89	90	121	102	90	85	77	85	90	71	90	100	87
18–19	90	103	98	114	97	99	83	84	92	90	66	92	103	91
19–20	82	102	95	124	100	106	81	88	88	86	53	91	105	90
20–21	85	98	96	125	103	112	86	92	103	86	64	95	106	94
21–22	82	96	105	117	104	108	87	94	93	95	72	96	106	92
22–23	80	94	98	123	102	100	86	89	92	103	77	95	104	89
23–24	80	94	93	119	98	108	88	91	86	105	72	94	101	92
Mean	92	109	113	130	117	112	107	92	94	100	85	104	117	103
No. days recorded	26	24	23	24	24	25	27	18	18	22	26	257	95	78

[a]November, 1932, to February, 1933. [b]October, 1932, March and April, 1933. [c]May to August, 1933.

Results—Summaries of the recorded elements are given in Tables 1-7 for each month, for three seasons, and for the eleven-month period. The months used for the seasons are: November, December, January, and February for winter; October, March, and April for the equinoctial; May, June, July, and August for summer. Instrumental difficulties and large rapid variations in the elements resulted in some loss of record which accounts for the incomplete registration on some days. The first factor was mainly responsible for the loss of record of potential-gradient during the winter while the second predominated during the summer. Instrumental difficulties accounted for most of the incomplete registration of the conductivity.

The mean hourly values of gradient given in Table 1 are based on all days for which complete and satisfactory records were obtained. The selected days of potential-gradient given in Table 2 were taken on the basis of lack of variability in the record, an attempt being made to select ten days of each month. First all days having negative potentials were rejected, then from the remainder those showing the smallest irregular departures from a smooth curve were selected. This gave a selective group during the winter when the percentage of zero-days, that is, days

ABLE 2—*Mean hourly values of atmospheric potential-gradient in volts per meter, for selected zero days, October 1932 to August 1933, College-Fairbanks Polar Year Station*

(Tabular values are averages of 60-minute means centering on the half-hour)

vest .T. rs	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Means: 11 months	Means: Winter[a]	Means: Equinox[b]	Means: Summer[c]
1	77	85	94	113	93	101	85	83	97	81	81	90	96	88	86
2	76	104	102	113	93	95	90	85	96	75	81	92	103	87	84
3	85	100	111	116	91	100	83	98	89	80	82	94	104	89	87
4	88	96	114	120	104	104	94	105	102	84	83	99	108	95	94
5	90	96	106	116	114	112	102	110	115	87	87	103	108	101	100
6	92	98	103	112	116	109	107	111	105	96	93	104	107	103	101
7	88	100	105	114	114	114	110	121	107	91	96	105	108	104	104
8	99	106	111	124	114	120	130	116	100	92	106	111	114	116	104
9	107	133	118	141	127	130	115	110	110	97	119	119	130	117	109
10	101	131	124	139	134	127	125	105	105	92	120	118	132	118	106
11	100	125	132	140	132	120	126	99	100	94	115	117	132	115	102
12	100	124	110	123	123	113	115	104	92	92	106	109	120	109	98
13	87	92	110	112	113	104	105	100	88	82	95	99	107	99	91
14	77	93	100	110	96	99	102	89	89	84	93	94	100	93	89
15	74	89	91	103	89	84	88	84	81	81	90	87	93	82	84
16	75	81	102	84	90	81	87	82	74	77	87	84	89	81	80
17	76	80	96	89	90	78	79	79	74	78	83	82	89	78	78
18	70	80	86	95	91	75	83	85	77	80	76	82	88	76	80
19	72	96	87	94	88	79	77	90	86	74	77	84	91	76	82
20	74	96	85	100	96	82	79	92	87	70	68	84	94	78	79
21	76	95	82	120	103	82	81	92	127	74	71	91	100	80	91
22	79	96	95	116	105	83	89	90	115	83	75	93	103	84	91
23	72	93	85	110	102	92	76	86	116	86	81	91	98	80	92
24	76	91	86	111	92	93	82	89	102	84	79	90	95	84	88
an	84	99	101	113	105	99	96	96	97	84	89	97	105	93	92
ays led	10	10	10	10	10	10	10	10	8	10	10	108	40	30	38

Iovember, 1932, to February, 1933. [b]October, 1932, March and April, 1933. [c]May to August, 1933.

TABLE 3—*Summary of Fourier analyses of diurnal variation of the potential-gradient for selected days, October 1932 to August 1933, College-Fairbanks Polar Year Station*

(Phase-angles are based on Greenwich mean time)

Period	Phase-angles				Amplitudes								Mean	Ra…
	ϕ_1	ϕ_2	ϕ_3	ϕ_4	C_1		C_2		C_3		C_4			C_2…
	°	°	°	°	*v/m*	*per cent*	*v/m*	*per cent*	*v/m*	*per cent*	*v/m*	*per cent*	*v/m*	
Winter	182	218	242	3	14.3	14	8.9	8	4.3	4	4.0	4	105	0.
Equinox	179	223	256	318	18.4	20	6.4	7	1.3	1	0.8	1	93	0.
Summer	192	242	108	331	11.0	12	6.0	7	1.9	2	1.8	2	92	0.
Eleven Months	183	225	228	348	14.2	15	7.0	7	1.6	2	2.1	2	97	0.

TABLE 4—*Mean hourly values of positive-conductivity of atmosphere in* 10^{-6} *esu, for all complete days, October 1932 to August 1933, College-Fairbanks Polar Year Station*

(Tabular values are averages of 60-minute means centering on the half-hour)

150° west M.M.T. hours	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Means: 11 months	Winter[a]	Equinox[b]
0– 1	265	187	211	166	178	191	182	187	152	119	174	183	186	213
1– 2	281	182	212	177	174	191	184	183	153	122	175	185	186	219
2– 3	280	184	214	169	172	185	184	181	152	124	175	184	185	216
3– 4	285	205	218	174	182	197	190	184	157	129	181	191	195	224
4– 5	272	217	232	178	190	199	196	183	165	132	183	195	204	222
5– 6	274	222	238	181	192	199	203	198	165	133	187	199	208	225
6– 7	278	223	235	177	181	191	195	184	166	129	192	196	204	221
7– 8	259	205	223	162	167	176	182	184	166	133	188	186	189	206
8– 9	252	177	200	156	146	167	172	176	157	132	164	173	170	197
9–10	265	167	189	152	149	165	164	176	151	129	162	170	164	198
10–11	258	172	166	147	146	172	162	175	154	120	159	166	158	197
11–12	228	167	166	154	152	175	169	168	153	122	160	165	160	191
12–13	223	169	159	140	150	185	176	172	148	121	166	164	154	195
13–14	226	173	168	143	160	181	179	170	150	123	167	167	161	195
14–15	237	193	187	148	169	193	189	171	144	120	167	174	174	206
15–16	238	205	187	151	173	195	198	168	144	119	171	177	179	210
16–17	240	195	187	150	158	200	199	169	138	123	170	175	172	213
17–18	246	205	195	150	155	188	203	178	138	124	169	177	176	212
18–19	248	198	197	159	170	182	208	181	145	123	166	180	181	213
19–20	247	193	195	159	165	192	208	187	141	117	165	179	178	216
20–21	242	194	185	156	169	197	206	183	143	120	166	178	176	215
21–22	243	188	186	161	158	195	206	185	139	120	165	177	173	215
22–23	245	193	193	166	162	193	197	186	146	117	167	179	178	212
23–24	253	184	200	158	161	191	195	180	145	120	176	178	176	213
Mean	254	192	198	160	166	188	189	180	150	124	171	179	179	210
No. days recorded	28	29	27	29	24	27	28	21	25	26	20	284	109	83

[a]November, 1932, to February, 1933. [b]October, 1932, March and April, 1933. [c]May to August, 1933.

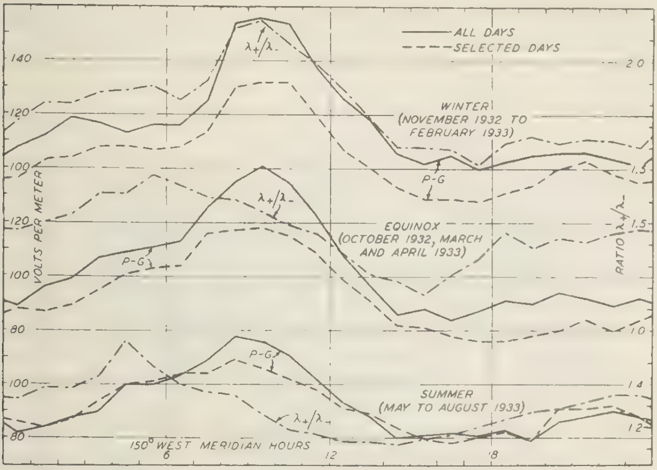

FIG. 6—AVERAGE HOURLY POTENTIAL-GRADIENT (P-G) FOR ALL DAYS AND SELECTED DAYS, AND RATIO OF POSITIVE TO NEGATIVE AIR-CONDUCTIVITY (λ_+/λ_-) FOR ALL DAYS, COLLEGE-FAIRBANKS (ALASKA) POLAR-YEAR STATION, OCTOBER 1932 TO AUGUST 1933

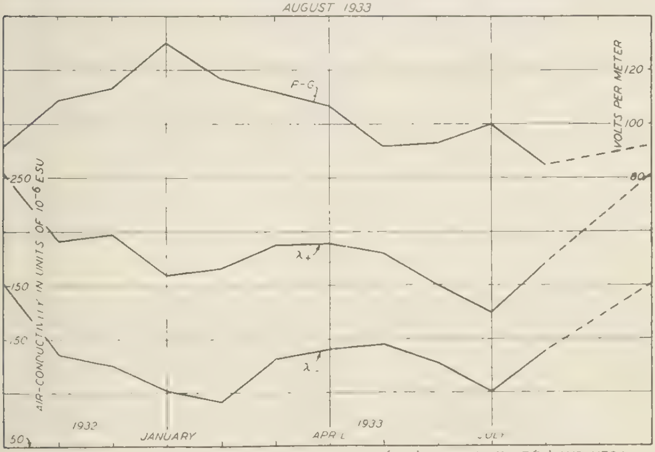

FIG. 8—AVERAGE MONTHLY POTENTIAL-GRADIENT (P-G), AND POSITIVE (λ_+) AND NEGATIVE (λ_-) AIR-CONDUCTIVITY, COLLEGE-FAIRBANKS (ALASKA) POLAR-YEAR STATION, OCTOBER 1932 TO AUGUST 1933

free from negative potentials, was large, but during the summer when the negative potentials occurred much more frequently, the selection from zero-days was not so discriminate. For example, during the month of June there were but eight complete days recorded which were free from negative potentials, so all were used in the selected group. The diurnal course in gradient is shown for the three seasons, for all complete days, and for selected days in Figure 6. It will be noticed that although

TABLE 5—*Mean hourly values of negative-conductivity of atmosphere in* 10^{-6} *esu, for all comple days, October 1932 to August 1933, College-Fairbanks Polar Year Station*
(Tabular values are averages of 60-minute means centering on the half-hour)

150° west M.M.T. hours	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Means: 11 months	Means: Winter[a]	Means: Equinox[b]
0– 1	211	135	140	105	99	129	131	141	129	94	133	132	120	157
1– 2	223	127	131	109	98	128	127	137	130	100	128	131	116	159
2– 3	216	123	126	105	95	124	127	134	126	97	131	128	112	156
3– 4	216	135	130	108	92	123	124	132	127	96	133	129	116	154
4– 5	202	140	138	106	97	116	125	129	122	95	126	127	120	148
5– 6	197	143	144	110	105	109	129	135	133	103	130	131	126	145
6– 7	212	146	139	113	96	112	130	139	132	98	136	132	124	151
7– 8	197	122	135	98	81	109	124	142	131	106	138	126	109	143
8– 9	186	99	119	87	65	108	124	144	128	103	130	118	92	139
9–10	200	101	104	81	69	111	121	150	131	104	136	119	89	144
10–11	200	114	93	89	71	123	124	148	137	103	134	121	92	149
11–12	182	109	102	97	78	126	131	150	133	104	139	123	96	146
12–13	188	117	100	93	83	140	137	153	134	105	149	127	98	155
13–14	195	126	113	95	93	144	148	159	136	107	145	133	107	162
14–15	205	151	128	106	109	159	161	158	134	105	144	142	124	175
15–16	202	173	124	109	104	156	167	155	125	106	145	142	128	175
16–17	204	159	130	104	97	160	166	152	128	112	148	142	122	177
17–18	202	171	141	103	95	149	163	153	129	106	140	141	128	171
18–19	203	156	136	107	99	142	157	148	128	97	138	137	124	167
19–20	202	142	136	104	100	146	158	147	125	93	144	136	120	169
20–21	191	139	127	105	99	141	154	149	118	96	142	133	118	162
21–22	195	141	122	103	93	140	154	146	113	91	137	130	115	163
22–23	198	143	136	111	94	136	146	140	115	91	137	132	121	160
23–24	201	142	140	107	98	134	141	136	120	89	137	131	122	159
Mean	201	136	126	102	92	132	140	145	128	100	138	131	114	158
No. days recorded	26	27	28	31	23	27	30	23	23	22	24	284	109	83

[a]November, 1932, to February, 1933. [b]October, 1932, March and April, 1933. [c]May to August, 1933.

selected days give slightly lower values for the gradient than do all days—particularly during the winter and equinoctial seasons—the character of the diurnal variation is much the same for both.

Table 3 summarizes the harmonic analyses of the mean of selected days of potential-gradient for three seasons and for the eleven-month period; it gives the constants for the first four terms of the harmonic series $\Sigma C_n \sin (n\theta+\phi_n)$, which defines the diurnal variation, the mean values in volts per meter, and the ratio C_2/C_1. The phase-angles are based on Greenwich mean time so that $\theta=0°$ corresponds to Greenwich midnight. The amplitudes are given both in volts per meter and in percentage of the mean value. The phase-angles, in general, agree well with those found by Mauchly. These analyses do not show any significant change of phase with season, either in the first or second harmonic, nor is the amplitude of the second harmonic proportionately greater in summer, as has been observed elsewhere.

All values of volts per meter which are given were derived from the air-potential recorded at the variation-observatory by multiplying by 1.09 for the entire series. Although large variations in the ratio of the

BLE 6—*Mean hourly values of positive-conductivity of atmosphere in 10^{-6} esu, for selected days, October 1932 to August 1933, College-Fairbanks Polar Year Station*

(Tabular values are averages of 60-minute means centering on the half-hour)

est T. s	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Means			
												11 months	Winter[a]	Equinox[b]	Summer[c]
1	279	200	223	184	178	211	186	177	139	154	175	191	196	225	161
2	285	176	228	185	187	213	195	176	138	157	171	192	194	231	160
3	282	174	228	177	189	205	194	171	145	166	165	189	192	227	162
4	294	219	233	191	188	209	199	172	162	177	167	201	208	234	170
5	298	236	245	194	190	212	213	174	176	171	183	208	216	241	176
6	297	244	252	206	193	207	218	194	175	168	207	215	224	241	186
7	294	240	250	192	187	196	211	176	174	172	197	208	217	234	180
8	282	223	240	178	192	190	184	184	171	167	198	201	208	219	180
9	282	200	231	161	166	181	188	182	158	154	177	189	190	217	168
0	288	186	208	159	163	185	172	170	150	155	178	183	179	215	163
1	279	204	187	169	165	192	168	179	158	150	157	183	181	213	161
2	240	204	197	172	150	196	164	172	155	158	156	179	181	200	160
3	224	190	194	159	158	190	176	177	154	160	178	178	175	197	167
4	241	190	204	155	180	184	172	169	145	155	173	179	182	199	160
5	257	208	222	177	187	201	186	158	141	152	174	188	198	215	156
6	244	220	206	189	192	203	190	162	135	150	170	187	202	212	154
7	237	196	196	188	181	208	190	157	141	160	173	184	190	212	158
8	243	233	211	181	178	207	201	167	138	159	168	190	201	217	158
9	250	189	223	162	181	206	211	166	147	152	167	187	189	222	158
0	257	199	231	189	156	217	206	172	131	146	176	188	194	227	156
1	244	193	238	170	166	216	209	174	108	144	175	185	192	223	150
2	239	197	232	180	155	212	204	183	107	153	181	186	191	218	156
3	265	193	242	192	160	216	208	188	125	153	180	193	197	230	162
4	271	187	244	157	185	209	203	184	122	158	191	191	193	228	164
n	266	204	224	178	176	203	194	174	146	158	177	190	195	221	164
ys ed	8	8	10	8	8	9	10	6	7	7	7	88	34	27	27

ovember, 1932, to February, 1933. [b]October, 1932, March and April, 1933. [c]May to August, 1933.

gradient at the field-station to the air-potential at the variation-observatory were found, which are of interest for special studies, still no significant seasonal changes greater than ten per cent were noted. Therefore in reducing the data it was considered satisfactory to consider the factor as constant for the entire period. The value 1.09 was derived from approximately 3600 hours of simultaneous records.

The mean values of conductivity given were not necessarily derived from the same days used to determine the mean values of gradient. The values for positive conductivity given in Table 4 and those for negative conductivity given in Table 5 are based on all days for which the records were complete and satisfactory. The values for selected days given in Tables 6 and 7 were derived using all days selected for the potential-gradient group which were also complete for the conductivity of both signs. The mean hourly values of the conductivity for the three seasons are shown for all days and for selected days in Figure 7. It will be noticed that, although the graphs of gradient and conductivity are somewhat reciprocal in character, still an early morning maximum in conductivity tends to appear here as found at many other stations.

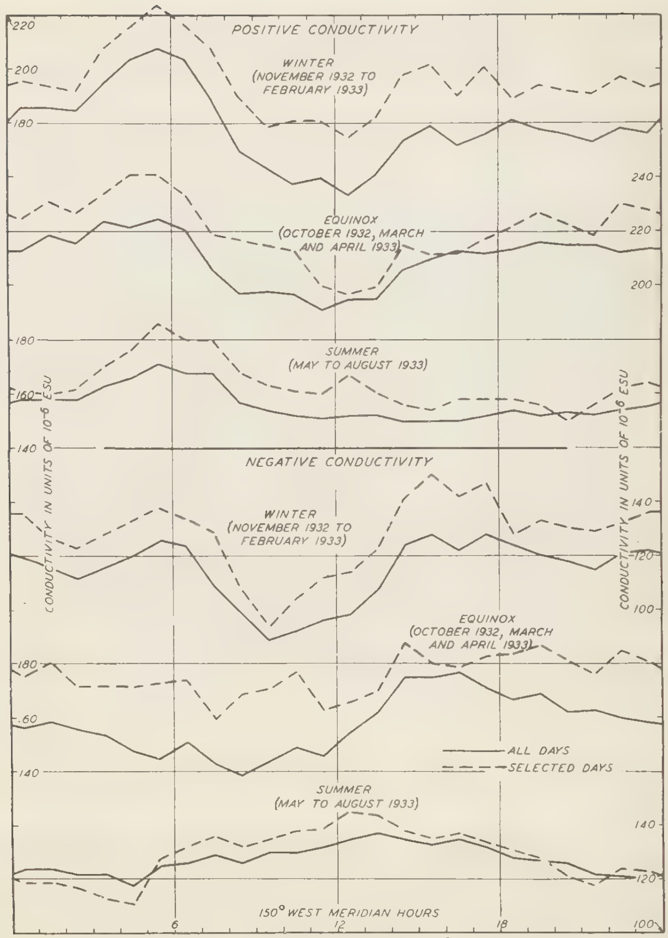

FIG. 7—AVERAGE HOURLY POSITIVE (λ_+) AND NEGATIVE (λ_-) AIR-CONDUCTIVITY FOR ALL DAYS AND SELECTED DAYS, COLLEGE-FAIRBANKS (ALASKA) POLAR-YEAR STATION, OCTOBER 1932 TO AUGUST 1933

This effect seems to be altered by a tendency for the conductivity to decrease in the morning due to the world-wide increase in gradient. The selected days for conductivity generally yield greater values than do all days, the potential-gradient values being correspondingly less.

The annual variation of the three recorded elements as derived from all days is shown in Figure 8. The seasonal maximum in gradient occurred in January as for many stations farther south, unlike the maximum in April found by Sverdrup in the arctic and unlike the maximum in summer and the minimum in winter found by Sheppard[7] at Fort Rae.

[7]P. A. Sheppard, British Polar Year Expedition, Fort Rae, N. W. Canada, 1932-33, 1, 309-333 (1937.)

BLE 7—*Mean hourly values of negative-conductivity of atmosphere in* 10^{-6} *esu, for selected days, October 1932 to August 1933, College-Fairbanks Polar Year Station*

(Tabular values are averages of 60-minute means centering on the half-hour)

est T. s	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Means: 11 months	Winter[a]	Equinox[b]	Summer[c]
1	219	144	158	129	111	172	137	145	96	117	119	141	136	176	119
2	235	121	146	124	118	170	137	133	106	125	111	139	127	181	119
3	213	122	138	117	116	159	144	121	112	123	112	134	123	172	117
4	220	150	146	126	92	156	140	105	117	117	113	135	128	172	113
5	228	170	150	123	90	146	142	108	111	113	112	136	133	172	111
6	233	175	151	126	99	139	148	128	128	133	125	144	138	173	128
7	238	168	154	122	94	138	145	122	133	138	133	144	134	174	132
8	219	152	161	111	92	133	129	130	129	137	146	140	129	160	136
9	213	123	140	94	74	142	151	142	126	126	133	133	108	169	132
0	225	118	113	81	66	151	137	143	128	129	140	130	94	171	135
1	234	140	106	94	74	163	135	154	134	135	127	136	104	177	138
2	186	138	130	108	74	168	135	149	135	141	130	136	112	163	139
3	190	137	130	103	85	164	144	154	134	141	151	139	114	166	145
4	207	139	143	110	98	158	144	154	132	140	149	143	122	170	144
5	218	159	160	128	117	182	163	138	134	136	145	153	141	188	138
6	195	183	136	156	125	183	162	140	125	134	140	153	150	180	135
7	185	159	138	144	125	186	166	140	129	136	143	150	142	179	137
8	204	190	154	130	113	181	164	143	121	134	136	152	147	183	134
9	209	142	156	108	105	180	164	142	123	127	133	144	128	184	131
0	221	149	170	128	84	181	160	140	109	122	139	146	133	187	128
1	200	154	167	107	92	180	163	140	90	120	134	141	130	181	121
2	195	150	165	107	94	176	157	150	78	114	131	138	129	176	118
3	220	142	176	121	89	174	161	150	85	121	138	143	132	185	124
4	219	140	180	110	113	167	156	144	87	120	141	143	136	181	123
n	214	149	149	117	98	165	149	138	117	128	133	141	128	176	129
ys d	8	8	10	8	8	9	10	6	7	7	7	88	34	27	27

vember, 1932, to February, 1933. [b]October, 1932, March and April, 1933. [c]May to August, 1933.

The conductivity, although somewhat reciprocal in character to the gradient, evidently depends also on other factors.

The number of small ions per cc and the derived mobility in $cm^2\ volt^{-1}\ sec^{-1}$ for each sign, are given in Table 8. The number of ions was calculated on the assumption that each unit-charge collected was due to the capture of a singly charged small ion. Simultaneous values of conductivity were scaled from the record and were used together with the ion-count to compute the mobility of the small ion from the relation $k=\lambda/ne$, k being the mobility, λ the conductivity, n the number, and e the unit-charge. An investigation into the effect of intermediate and large ions on the computed values was not made experimentally. However, theoretical considerations, taking into account the constants of the two apparatuses and the method of operation, show that the ionic current in the ion-counter would be much more affected by the presence of low-mobility ions than would that in the conductivity-apparatus. Therefore this method of calculating the mobility may yield values appreciably less than the true value. The individual determinations were grouped according to values of mobility ranging from 0.7 to 2.40

TABLE 8—*Mean values of positive and negative small ions in numbers per cc, mobility in cm² volt⁻¹ sec⁻¹, Aitken nuclei in number per cc, for all days November 1932 to August 1933, College-Fairbanks Polar Year Station*

(Tabular values derived from all satisfactory individual determinations)

Period	Value of element					Number of determinations				
	n_+	n_-	k_+	k_-	Nuclei	n_+	n_-	k_+	k_-	Nuclei
November	980	660	1.35	1.33	....	26	25	26	25	....
December	810	560	1.37	1.28	....	30	28	26	24	....
January	720	560	1.55	1.29	....	24	23	22	23	....
February	910	660	1.75	1.35	....	23	23	22	22	......
March	780	590	1.71	1.50	2070	27	27	26	27	5
April	710	570	1.72	1.86	5090	29	29	28	29	23
May	740	590	1.77	1.99	4640	25	25	22	23	18
June	710	540	1.50	1.70	2850	30	30	29	28	15
July	620	520	1.41	1.46	2390	29	29	25	22	26
August	750	570	1.53	1.68	4190	27	27	26	27	25
All	770	580	1.56	1.56	3760	270	266	252	250	112

from which the frequency-curves for both k_+ and k_- were drawn as shown in Figure 9. Seasonal changes in mobility due to changes in temperature, which may amount to 20 per cent, apparently are small in comparison with changes due to other factors. These curves suggest that groups of ions with but slightly different mobilities may be present. If this interpretation is adopted these results would indicate that the positive ions comprising the most prevalent group have a mobility of approximately 1.40 and that there are two other groups with mobilities

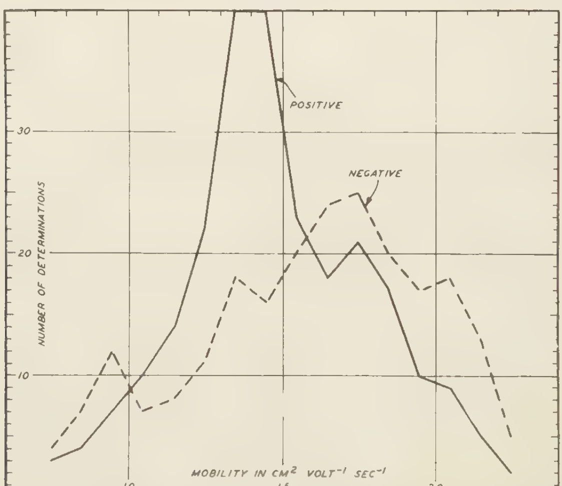

FIG. 9—FREQUENCY-DISTRIBUTION OF DETERMINATIONS OF MOBILITY, COLLEGE-FAIRBANKS (ALASKA) POLAR-YEAR STATION, NOVEMBER 1932 TO AUGUST 1933

of 1.75, and 2.05 cm^2 volt^{-1} sec^{-1}. The negative ions may perhaps be regarded as falling in four mobility-groups with the most prominent having a value of 1.75 and with three other groups having mobilities of 0.95, 1.45, and 2.05 cm^2 volt^{-1} sec^{-1}. These group-values, as also the overall mean values, are nearly equal for both signs of ions.

The Aitken nuclei-counter did not operate satisfactorily during extremely cold weather and so it was not until the latter part of March that apparently reliable counts were obtained; summaries of the observations are given in Table 8. The correlation between the individual counts of nuclei and the corresponding conductivity or small-ion counts is small, which is at variance with the usual and expected relation. Without measures of other factors contributing to the ionization-balance in the atmosphere it is impossible to definitely account for this lack of dependence of the number of small ions upon the numbers of Aitken nuclei. If the relations of Schweidler are accepted it would appear that either of three explanations are permissible. First, of course, the count of nuclei may be questioned; the only criterion available for appraising the reliability of these counts is that the counter appeared to work satisfactorily and in a similar manner to its operation at Washington where good correlation was found between the nuclei and other elements and where comparisons with results obtained with other counters were satisfactory. Second, the rate of production of small ions may be too variable at this station to allow one to regard this factor as constant as must be done in this correlation. Third, the equilibrium between small and large ions and between small ions and uncharged nuclei may be appreciably affected by factors not considered in the usual expressions for equilibrium and which may occur more frequently at College than at other stations where the necessary data for such comparisons have been obtained.

The examination for possible correlation between auroral displays and potential-gradient is being continued. It may be said that rapid changes in auroral activity are not associated with corresponding changes in potential-gradient and that no outstanding correlation such as was found to exist between the auroral data and earth-current potentials[8] is found. First indications are that the gradient is slightly depressed by auroral activity but an exhaustive statistical investigation will be required to establish whether this relation is significant.

That the electrode-effect must be taken into account when interpreting the relations between the elements at College is evident from a casual inspection of these data. This was because of the extremely calm condition which prevailed there during the period of registration. This was particularly noticeable in winter when falling snow would accumulate on twigs of trees and on the wires of power-lines to depths exceeding four cm and, although dry and powdery, would remain there for days before a wind occurred with sufficient force to dislodge it. Records of wind-run show mean values during the winter of approximately one meter per second with practically no diurnal variation. Evidence for the electrode-effect may be seen in Figure 6 where the diurnal variation of the ratio of positive to negative conductivity is shown for comparison with the gradient. The ratio is seen to vary considerably and to follow very closely variations in the gradient, particularly in winter.

[8] W. J. Rooney, *loc. cit.*

In summer not only are the ratio and gradient less, but increased turbulence and variations in other factors have changed the character of the dependence. It is planned to discuss in more detail these and other features of the results in a subsequent issue of this Journal.

The author wishes to acknowledge his indebtedness to those organizations which cooperated to make the project possible. His thanks extend to the numerous individuals who directly and indirectly are responsible for the accumulation and preparation of these data and who by their good-will made participation so pleasant. In particular he would thank Dr. J. A. Fleming and O. H. Gish, Director and Assistant Director, respectively, of the Department of Terrestrial Magnetism, the former of whom was largely responsible for the successful establishment of the College-Fairbanks Station, while the latter designed much of the apparatus and planned and supervised this work; Dr. C. E. Bunnell, President of the University, who so generously made the facilities of the University available; E. R. Johnson and H. F. Bennett, full-time members of the staff of the Observatory, and the members of the faculty of the University who assisted directly in obtaining these data.

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FINAL RELATIVE SUNSPOT-NUMBERS FOR 1936 AND MONTHLY MEANS OF PROMINENCE-AREAS FOR 1909-1936

By W. Brunner

Table 1 contains the final sunspot-numbers for 1936, for the whole disc of the Sun, based on observations made at the Zürich Observatory, supplemented by series furnished by other cooperating observatories

Table 1—*Final relative sunspot-numbers for the whole disc of the Sun for 1936*

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
56[d]	45	74[a]	W 93[ac]	M 29[c]	77	ME 79[cc]	66	E 110[c]	113	118[d]	193[bdd]
70	E 45[c]	68	100	44	97	74	64[ab]	68	E 98[c]	137[a]*	179[b]*
61[b]	46	60[a]	91[a]	47	65[b]	44	74	77	W 103[ac]	E 149[ac]	176[a]*
69	43	55[a]	E 74[c]	E 57[c]	M 62[ac]*	50	65[d]	57	112	144[ad]	161*
63	W 67[ac]	M 69[c]*	85	47	62	M 52[ac]	M 87[c]	M 68[c]	122	159	158
55	56[a]	60[a]	91[d]	36	66*	37	86	65[a]	137[bd]	E 151[acd]	E 146[c]
37[a]	W 61[cd]	M 83[c]	86[b]*	M 46[cd]	E 69[c]	30	89	46	E 138[c]*	127[ad]	116[aa]*
37	93	89	76[b]	46	73	47[d]	E 89[c]	53[a]	122*	E 140[cd]	E 134[c]
41	84	E 88[c]	89[d]	46	64	43	107	42	107	127	104
29	73[a]	92[ad]	99	40	40[a]	47	W 89[ac]	40	81	150	107[a]
34[d]	60[a]	79	91[a]	54[d]*	35	E 49[c]	83[a]	49[d]	81[ad]*	E 148[ac]	82[d]
38	93	67[a]	E 92[c]	49	E 40[c]	67	70[a]	E 70[c]	M 82[ac]	138[aa]	W 76[c]
44[d]	69[b]	E 59[c]	83[a]	71[a]	43	67	M 88[c]	W 94[c]	76[a]	139[a]*	74[d]
62*	M 77[c]	69	86	73	32	76[b]	103	77[d]	92	117[ab]*	71
70[c]	77[a]	56	73[a]	68	19[d]	67	E 122[acd]	64	WM 123[cc]	119	40
56	91[d]	61[a]	88[ad]	67	55	69[d]	93	71	104[ad]	95	43
58[a]	58[a]	60	88*	64[a]	67	67	105	63[a]	105	E 95[c]	W 71[ac]
79	55	M 66[c]	73	47	60	53	115	E 66[cd]	82[a]	61	88[d]
83[b]	56	M 87[acd]	83	36	101	49	89[a]	58	80[a]	60	85[a]
87[a]	74	112	75	26	88	43	64	74	85	40*	74
99[d]	E 111[ccd]	104	67[a]	45	119[bd]	28	71[a]	E 80[acd]	65[d]	29	86[dd]
98*	97[aaa]	96	49[a]	49*	100[b]	27[a]	63[a]	116	55	40[b]	117
104	87	82	56	44*	W 76[c]	M 30[c]	64[ad]	M 128[ac]	63	48[d]	130
107[d]	109[d]	53	E 53[c]	M 85[cd]	71	36	63[d]	90[a]	52	44	E 149[accd]
85	90[a]	E 49[c]	W 72[c]	71	M 89[c]	42	E 90[c]	E 89[ac]	35	E 70[cd]	153
72	97[d]	65[ad]*	77	78	112[a]	49	75[a]	M 85[ac]	M 40[c]	99	152[a]
75[a]	91[a]	78[d]*	55	65	103[a]	38	87[a]	95[d]*	52[aad]	145[d]	164[a]
50	E 85[c]*	M 98[c]	48*	68[d]	68	47[d]*	89	94[a]	77	E 218[c]	135[ad]
49*	64	98	32	68	68	WE 59[cc]	M 106[acd]	86	86[d]*	197[ad]	E 170[acd]
37[ad]		E 103[ac]	21*	48[a]	79	61	123[b]	106[ad]	95	162*	E 205[ac]
42		109[a]		W 78[c]		93[b]	118		95[d]		187
62.8	74.3	77.1	74.9	54.6	70.0	52.3	87.0	76.0	89.0	115.5	123.4

ssage of an average-sized group through the central meridian.
ssage of a large group or spot through the central meridian.
w formation of a center of activity: *E*, on the eastern part of the Sun's disc; *W*, on the western part; *M*, in the cen-
le zone.
ntrance of a large or average-sized centre of activity on the east limb.

for days (indicated by asterisks) on which no observations were possible at Zürich.

Table 2 gives the yearly means of the relative numbers, R, since the last minimum 1933 and the number of days without spots.

TABLE 2—*Yearly means of relative sunspot-numbers, R*

Year	R	Increase	No. spotless days
1933	5.7		240
1934	8.7	3.0	154
1935	36.1	27.4	20
1936	79.7	43.6	0

Figure 1 gives a graphical representation of the daily relative sunspot-numbers for 1936, the times being plotted as abscissas and the relative numbers as ordinates. The limits of the successive solar rotations are indicated by vertical arrows in the upper edge of the Figure. The secondary maxima and minima succeeding the rotation-periods do not represent real fluctuations in sunspot-activity, but are rather to be attributed to the influence of solar rotation, to a certain stability of the centers of activity for spots, and to the special distribution of these centers of activity in the direction of rotation.

Figure 2 shows the observed and smoothed monthly relative numbers for 1923 to 1936. The purpose of smoothing is to eliminate the secondary variations. The method of smoothing is as follows: For obtaining the

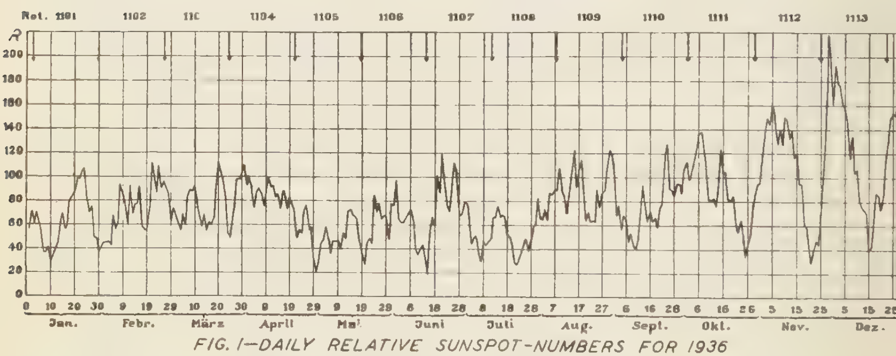

FIG. 1—DAILY RELATIVE SUNSPOT-NUMBERS FOR 1936

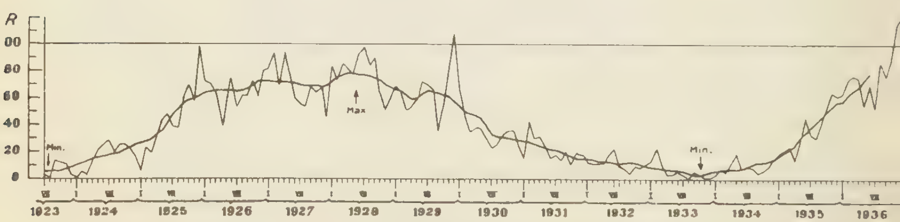

FIG. 2—OBSERVED AND SMOOTHED MONTHLY RELATIVE NUMBERS FOR 1923 TO 1936

TABLE 3—*Monthly means of prominence-areas for 1909-1936*[1]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Yearly means
1909[2]	367 29	558 25	550 27	410 34	394 30	333 27	511 32	475 32	560 29	383 26	496 21	423 25	455 337
1910[2]	374 28	587 26	636 31	630 30	339 29	320 30	362 30	271 30	208 27	247 27	246 27	236 25	371 340
1911[2]	192 29	243 25	189 27	220 31	157 28	199 29	192 31	204 31	145 25	167 31	141 24	139 14	182 326
1912	104 6	45 13	102 14	136 12	101 10	97 11	101 12	240 7	103 7	198 9	217 10	73 9	126 120
1913	58 5	132 16	153 16	105 10	127 15	68 8	169 10	198 7	176 5	95 12	79 5	104 5	122 114
1914	73 5	261 7	128 4	212 15	290 8	377 16	326 13	559 18	286 11	687 13	417 3	533 8	346 121
1915	584 2	395 5	751 7	751 14	705 7	664 10	898 12	1040 8	943 11	802 3	820 6	1074 2	785 87
1916	498 6	1127 8	827 4	1087 14	1004 11	711 7	557 13	751 10	758 7	909 11	880 5	847 4	830 100
1917	1225 3	1134 11	618 5	785 6	842 14	1374 20	1790 13	1688 11	1627 13	1247 8	822 6	1097 3	1187 113
1918	930 7	763 7	1173 16	716 6	926 18	1567 14	1248 14	1010 11	660 6	978 9	595 8	554 3	927 119
1919	735 3	586 9	741 8	808 6	1172 19	1105 15	695 13	751 16	272 12	369 8	307 7	436 1	665 117
1920	816 7	640 14	583 12	1087 6	775 21	622 15	659 18	589 14	1123 4	923 11	725 8	— 0	777 130
1921	795 8	858 15	701 22	518 9	586 16	565 12	600 24	460 16	586 11	599 17	355 8	296 3	577 161
1922	177 3	277 4	378 11	466 11	501 22	427 16	648 14	351 14	573 7	394 6	560 11	637 6	449 125
1923[3]	370 8	283 11	342 14	481 16	432 22	392 18	386 24	351 29	302 20	385 16	395 15	485 4	384 197
1924	372 6	312 6	393 16	598 9	407 13	492 11	518 17	506 7	390 11	840 18	781 11	522 15	511 140
1925	575 14	456 13	413 10	702 10	548 15	727 21	718 14	665 18	878 11	783 7	— 0	755 4	657 137
1926	1323 8	1525 9	1532 8	1433 10	1342 9	1172 13	1229 15	1392 31	1198 32	1207 14	881 10	1185 3	1285 162
1927	1052 5	1050 16	1009 11	868 14	988 27	889 23	1014 21	765 24	858 14	649 23	720 7	742 4	884 192
1928	576 7	811 16	680 16	687 13	686 14	878 18	951 28	957 18	1123 18	798 15	975 8	911 4	836 175
1929	1056 8	806 15	942 19	828 15	712 18	754 18	916 24	858 24	936 30	1030 13	954 13	624 7	868 204
1930	748 11	748 12	467 13	770 17	640 10	420 28	363 19	316 26	266 13	268 10	232 12	414 9	471 180
1931[4]	193 9	279 9	197 20	255 15	362 21	294 25	468 25	656 22	552 22	655 32	480 19	494 25	407 245
1932[5]	518 23	513 30	511 23	445 18	338 17	443 23	437 23	376 34	440 21	302 18	363 27	439 17	427 274
1933[5]	404 17	426 15	396 34	323 18	329 16	565 18	568 39	460 32	597 17	582 23	319 12	376 24	445 265
1934[5]	480 15	427 35	387 20	431 31	539 34	592 26	616 32	493 19	763 30	625 27	542 19	438 17	528 305
1935[6]	751 14	573 11	715 27	897 7	896 19	738 26	885 25	1206 22	1399 26	1058 8	1155 14	1505 9	981 208
1936[5]	1005 6	987 15	868 23	1071 5	1284 19	905 18	790 20	965 31	1094 17	1314 21	1505 15	1531 14	1110 208

[1]The small numbers indicate the number of monthly observations.
[2]Zürich, Catania, Kalocsa, Madrid, Odessa, Rome, and Zô-Sè.
[3]Zürich and Dr. Scholl at Tölz.
[4]Zürich and Arosa from August 1931.
[5]Zürich and Arosa.

mean of the epoch July 1, the average of the monthly means of the twelve months January to December is taken (m_1), and for the epoch August 1, the average of the monthly means for February to January (m_2). The mean of these $m=(m_1+m_2)$ 2, which represents the smoothed relative number for the middle of July, is used for the construction of the curve.

To this summary of spot-activity for the last year I am adding Table 3 showing the activity of the prominences by monthly means of the measured areas for the period 1909 to 1936.

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THE MAGNETIC CHARACTER OF THE YEAR 1936 AND THE NUMERICAL MAGNETIC CHARACTER OF DAYS 1936

By G. van Dijk

The annual review of the "Caractère magnétique de chaque jour" for 1936 has been drawn up in the same manner as for the preceding years[1]. Fifty-four observatories contributed to the quarterly tables; fifty-two of them sent complete data.

Table 1 (reproduced from Table II of the annual review) contains the mean character of each day for each month. The lists of calm days and disturbed days, and the days recommended for reproduction are also reprinted here as Table 2.

[1]Terr. Mag., **33**, 203 (1928); **34**, 207 (1929); **35**, 178 (1930); **36**, 255 (1931); **37**, 259 ,(1932); **38**, 301-302 (1933); **39**, 237-238 (1934); **40**, 383-384 (1935); **41**, 351-352 (1936).

BLE 1—*Mean magnetic character numbers for each day of 1936 from data supplied by 52 observatories*

Month	Dates														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1936															
January.....	0.2	0.1	0.1	0.1	0.2	0.1	0.1	1.2	1.0	1.2	0.8	1.1	1.2	0.6	0.2
February....	0.2	1.0	0.6	0.7	0.1	0.2	0.2	0.3	1.1	1.2	0.7	0.2	0.0	1.1	0.9
March......	0.2	0.2	0.1	0.1	0.5	0.7	0.1	1.0	0.8	0.3	0.0	0.1	0.3	0.2	0.7
April........	1.1	0.9	1.3	0.5	0.0	0.2	0.5	0.9	0.3	0.1	0.4	0.9	1.1	0.9	1.2
May........	0.6	0.2	0.1	1.1	0.3	0.2	0.2	0.1	0.0	1.2	1.3	1.5	0.6	0.9	0.8
June........	1.2	1.5	0.8	0.4	0.2	0.0	0.2	1.0	1.8	1.2	0.8	0.4	0.6	1.0	1.0
July........	0.2	1.8	0.8	0.2	1.2	1.5	1.0	0.8	0.3	1.5	1.5	0.9	0.9	0.1	0.1
August......	0.7	0.6	0.5	0.2	0.8	0.9	0.0	0.9	0.7	0.9	0.1	0.5	0.3	0.4	0.4
September...	0.1	0.4	0.1	0.6	0.4	0.1	0.0	0.7	0.8	0.6	1.2	0.5	0.1	0.2	0.3
October.....	0.5	0.1	0.1	0.2	0.9	1.1	1.1	1.0	1.2	1.4	0.5	0.1	0.3	0.7	1.0
November...	0.3	0.8	1.6	0.9	0.8	0.7	0.9	0.8	1.0	0.9	1.6	0.7	0.0	0.3	1.2
December...	0.8	0.5	0.7	1.0	0.7	0.7	0.7	0.3	0.1	0.1	0.1	0.8	0.8	0.7	0.1

Month	Dates																Means
	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
1936																	
nuary.....	0.0	0.2	1.3	0.8	0.6	0.9	0.8	0.6	1.7	1.4	1.4	0.8	0.9	0.7	0.7	0.6	0.69
ebruary..	1.5	1.5	0.6	1.6	0.7	1.3	1.3	1.1	0.6	0.8	1.2	1.1	0.1	0.6			0.78
arch......	0.2	0.7	0.8	0.8	1.2	1.4	1.1	1.4	1.5	1.3	1.0	1.1	0.6	0.5	0.2	0.5	0.64
pril.......	0.6	1.1	1.6	1.5	1.5	1.7	1.7	1.4	0.8	0.6	0.1	0.3	0.6	0.1	0.4		0.82
ay........	1.3	0.9	1.5	1.3	1.0	0.8	0.3	0.1	0.0	0.2	0.7	0.4	0.6	1.3	1.1	1.0	0.70
ne........	0.9	0.4	0.9	1.9	1.1	0.2	0.3	0.0	0.6	0.2	0.8	0.4	0.3	0.1	0.1		0.69
ly........	0.9	1.1	0.9	0.4	0.5	0.1	0.2	0.0	0.1	0.5	0.2	0.6	0.8	1.7	0.7	0.8	0.73
ugust......	0.2	0.2	0.0	0.1	0.4	0.3	0.2	0.1	0.2	0.6	0.4	0.8	0.4	0.5	1.2	0.7	0.45
ptember...	0.1	0.2	0.6	0.2	0.1	0.4	0.8	0.9	0.2	0.1	1.4	0.8	0.6	1.0	0.2		0.46
ctober.....	1.7	1.7	0.9	0.6	0.8	0.2	0.0	0.8	1.6	0.6	0.2	0.0	0.1	0.2	0.1	1.7	0.69
ovember...	1.0	0.9	1.0	0.9	0.5	0.3	0.0	0.0	0.0	0.1	0.6	0.1	0.7	2.0	0.4		0.70
ecember...	0.2	0.1	0.2	0.1	0.4	0.8	0.1	0.2	0.1	0.1	0.1	1.2	1.8	0.7	0.3	0.2	0.47

Table 2—*Dates of five magnetically calm and five disturbed days with mean character-numbers during*

Month	Calm days						Disturbed days				
1936											
January.....	(0.07)	**3,**	**4,**	**6,**	**7,**	**16**	**8** (1.2),	**18** (1.3),	**24** (1.7),	**25** (1.4),	**26** (
February....	(0.13)	**1,**	**5,**	**7,**	**13,**	**28**	**16** (1.5),	**17** (1.5),	**19** (1.6),	**21** (1.3),	**22** (
March......	(0.09)	**3,**	**4,**	**7,**	**11,**	**12**	**20** (1.2),	**21** (1.4),	**23** (1.4),	**24** (1.5),	**25** (
April........	(0.12)	**5,**	**6,**	**10,**	**26,**	**29**	**18** (1.6),	**19** (1.5),	**20** (1.5),	**21** (1.7),	**22** (
May........	(0.07)	**7,**	**8,**	**9,**	**23,**	**24**	**11** (1.3),	**12** (1.5),	**18** (1.5),	**19** (1.3),	**29** (
June........	(0.08)	**5,**	**6,**	**23,**	**29,**	**30**	**1** (1.2),	**2** (1.5),	**9** (1.8),	**10** (1.2),	**19** (
July........	(0.08)	**14,**	**15,**	**21,**	**23,**	**24**	**2** (1.8),	**6** (1.5),	**10** (1.5),	**11** (1.5),	**29** (
August......	(0.06)	**7,**	**11,**	**18,**	**19,**	**23**	**5** (0.8),	**6** (0.9),	**8** (0.9),	**10** (0.9),	**30** (
September...	(0.06)	**3,**	**7,**	**13,**	**16,**	**25**	**11** (1.2),	**23** (0.9),	**26** (1.4),	**27** (0.8),	**29** (
October.....	(0.07)	**2,**	**3,**	**22,**	**27,**	**28**	**10** (1.4),	**16** (1.7),	**17** (1.7),	**24** (1.6),	**31** (
November...	(0.03)	**13,**	**22,**	**23,**	**24,**	**25**	**3** (1.6),	**11** (1.6),	**15** (1.2),	**16** (1.0),	**29** (
December...	(0.07)	**9,**	**10,**	**19,**	**22,**	**24**	**4** (1.0),	**12** (0.8),	**13** (0.8),	**27** (1.2),	**28** (

Days recommended for reproduction

**June 19, November 29.
*April 17, April 22, October 16.

In the introduction a note has been inserted concerning the publication "Caractère magnétique numérique des jours" for 1936. Volumes XVIII to XXI have been published along with the tables of "Caractère magnétique de chaque jour."

Thirty-seven observatories have sent lists for 1936; thirty-five of them were complete.

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INTERNATIONALLY SELECTED MAGNETICALLY QUIET DAYS AND DISTURBED DAYS, 1895-1905

By G. van Dijk

Table 1—*Selected quiet days, 1895-1905*

nth	1895					1896					1897					1898				
y	13	14	27	28	31	1	2	23	26	28	6	9	20	21	22	3	4	7	9	23
ry	4	22	25	26	27	7	20	22	23	24	2	16	17	18	19	1	7	23	26	27
	11	12	21	24	29	17	18	19	21	24	16	18	20	21	26	3	4	7	25	29
	8	22	28	29	30	7	14	16	20	30	3	11	12	15	22	19	21	22	26	29
	4	12	16	25	26	5	26	27	28	31	8	9	26	27	28	19	21	23	24	25
	8	13	14	20	25	1	7	20	23	24	6	9	10	24	30	5	13	18	20	21
	7	10	18	19	25	9	17	19	28	31	5	13	18	26	29	2	14	15	16	18
	3	4	7	22	27	5	13	16	27	28	4	5	6	7	24	9	10	14	24	25
ber	2	7	8	11	28	1	9	11	27	28	2	8	19	26	28	6	7	19	21	26
r	3	10	22	24	25	6	7	26	27	28	8	13	14	20	21	4	11	12	17	18
ber	6	7	18	19	21	2	3	22	24	25	7	8	12	23	30	10	11	13	14	28
ber	6	16	28	29	31	8	12	18	19	20	8	13	26	27	28	10	12	23	25	26

nth	1899					1900					1901					1902				
y	8	9	10	25	27	3	7	8	9	30	12	13	16	19	20	1	12	14	21	22
ry	4	7	8	10	18	6	7	13	18	19	11	15	16	27	28	15	18	19	27	28
	5	19	20	27	30	5	11	21	27	28	5	10	15	16	28	4	14	19	20	28
	13	15	16	26	27	2	3	19	22	28	9	12	20	21	25	7	15	25	26	27
	13	14	25	28	29	9	10	15	16	27	5	13	16	17	22	3	11	12	16	22
	7	8	17	20	25	11	15	16	22	26	5	25	26	27	28	2	3	8	20	23
	19	22	23	30	31	1	3	9	13	15	3	21	28	29	30	2	6	14	21	31
	11	12	16	19	26	5	6	10	23	24	12	13	19	24	28	5	12	13	14	30
ber	5	6	7	8	20	7	11	12	21	25	7	8	19	20	25	8	9	14	24	26
r	2	10	11	29	30	1	2	15	19	31	2	3	23	30	31	7	10	14	16	22
ber	8	10	16	18	20	5	7	10	11	30	13	15	23	29	30	4	5	11	28	29
ber	6	11	14	15	24	5	6	20	21	23	14	15	16	17	23	5	8	14	18	31

nth	1903					1904					1905				
y	1	7	15	17	29	13	14	19	20	23	2	3	8	9	16
ry	1	2	18	27	28	18	20	21	27	28	11	18	19	20	28
	16	17	25	26	27	6	15	16	17	22	18	21	25	26	28
	14	16	20	22	23	14	16	23	27	28	11	17	18	23	24
	1	11	18	19	20	5	7	9	10	25	5	6	15	16	21
	6	12	13	26	27	3	13	24	29	30	13	18	19	27	28
	4	8	22	23	24	4	11	12	21	25	4	11	15	20	31
	3	7	19	29	31	24	25	26	27	28	1	9	10	15	18
ber	3	16	17	18	26	18	19	20	21	27	6	13	14	16	17
r	9	10	20	21	24	4	12	17	18	24	2	3	23	29	31
ber	14	15	25	27	28	9	12	13	19	20	1	2	11	20	29
ber	12	17	18	24	26	8	12	13	23	24	1	9	22	23	31

The selected quiet days for 1906 and following years will be found in the publication "Caractère magnétique de chaque jour." An annual summary also appears regularly in each volume of this Journal.

TABLE 2—*Selected disturbed days, 1895-1905*

Month	Year																		
	1895					1896					1897					1898			
January	1	6	17	18	19	3	4	19	30	31	1	2	3	29	30	15	16	17	18
February	9	10	15	16	24	3	4	14	28	29	3	4	25	26	27	11	12	14	15
March	8	9	13	14	22	4	12	26	27	28	3	4	8	10	29	11	15	16	18
April	5	6	11	12	23	21	22	23	24	25	2	6	20	23	24	4	7	12	13
May	2	10	28	29	30	2	3	17	18	20	2	14	17	21	30	4	11	12	29
June	2	3	4	17	30	9	14	16	17	29	2	3	16	17	18	7	8	15	26
July	1	13	14	15	27	4	5	12	23	27	14	15	22	30	31	20	21	22	23
August	9	10	11	18	23	1	2	7	21	29	1	9	15	20	30	3	16	17	22
September	4	5	15	19	20	3	17	18	20	24	4	5	11	14	23	3	9	10	28
October	12	13	14	17	27	1	9	10	11	12	1	2	10	18	28	22	25	28	29
November	9	10	11	23	24	5	6	7	8	9	17	18	20	24	25	17	18	20	21
December	7	8	9	21	24	3	4	5	13	14	11	12	20	21	31	5	14	15	16
	1899					1900					1901					1902			
January	15	18	23	28	29	5	15	19	20	26	2	5	22	23	24	15	16	17	24
February	12	14	23	24	28	4	5	9	11	24	2	19	20	22	23	7	8	20	21
March	10	11	21	22	23	1	8	9	13	14	18	19	23	24	29	8	11	12	24
April	5	10	18	19	29	5	9	10	11	30	1	2	14	15	27	8	10	11	20
May	3	4	5	15	31	1	3	5	6	30	10	11	23	24	31	8	9	10	18
June	1	27	28	29	30	2	5	27	28	29	1	7	13	14	21	6	15	21	22
July	2	3	4	6	25	17	20	24	25	28	11	12	17	18	20	8	12	24	25
August	3	20	21	29	31	1	7	8	20	27	3	14	15	16	31	9	16	21	22
September	1	15	18	26	27	5	15	16	22	23	10	11	12	16	17	2	12	18	19
October	5	6	15	23	24	4	20	25	26	27	8	9	13	25	28	11	24	27	30
November	4	19	22	23	30	1	2	13	18	24	4	5	9	11	19	14	22	23	24
December	2	18	19	28	29	2	7	10	27	28	1	2	9	27	28	9	12	13	23
	1903					1904					1905								
January	4	5	23	26	27	1	10	16	28	29	5	14	17	22	31				
February	8	12	13	15	22	5	6	7	9	16	3	4	5	14	23				
March	5	7	12	13	31	3	4	5	11	26	2	3	5	7	16				
April	5	6	9	18	26	1	2	4	18	19	1	2	3	5	29				
May	5	6	16	17	23	12	13	14	27	28	1	12	19	27	29				
June	1	2	28	29	30	6	15	16	17	27	5	9	10	22	23				
July	6	19	26	27	28	1	6	7	10	14	6	7	8	23	24				
August	11	12	21	22	26	2	3	4	21	30	2	3	7	29	30				
September	5	19	20	23	29	8	11	16	24	25	3	4	18	19	27				
October	12	13	14	26	31	7	8	13	21	22	6	13	18	26	28				
November	1	10	18	19	22	2	4	5	16	25	4	12	13	15	16				
December	4	13	20	30	31	3	9	14	15	16	4	12	13	20	29				

The selected dist[...] days for 1917 an[...] lowing years wi[...] found in the pu[...] tion "Caractère [...] nétique de chaque [...] An annual sum[...] also appears reg[...] in each volume o[...] JOURNAL.[a]

[a]For list of disturbed days during 1906 to 1914 see Trans. Edinburgh Meeting, 1936, Ass. Terr. Mag. Electr., Internat[...] Geod. Geophys., Bull. No. 10, p. 440 (1937).

ROYAL METEOROLOGICAL INSTITUTE OF THE NETHERLANDS,
De Bilt, September, 1937

SUMMARY OF THE YEAR'S WORK, DEPARTMENT OF TERRESTRIAL MAGNETISM, CARNEGIE INSTITUTION OF WASHINGTON[1]

By J. A. Fleming

Terrestrial magnetism—During the year ended June 30, 1937, the program of the Department was devoted not only to experimental investigation, but also to the coordination and integration of isolated researches that the inferences of each may be more broadly interpreted. Such a program cannot be consummated within a limited period so that reports of successive years must bear similarities outlining the general progress and application of experimental fact as it is revealed. During the year the common goal and unity of the several branches of research have been admirably demonstrated.

Thus the association of a special type of magnetic disturbance and sharp fade-outs of high-frequency radio-wave reflections with bright eruptions in the solar chromosphere, first pointed out by J. H. Dellinger, was conclusively proved by work of the Department in cooperation with Mount Wilson Observatory and other organizations. These effects are propagated from the Sun with the velocity of light. The active agent is believed to be ultra-violet light originating in the solar eruption which produces sudden and intense electrification of the Earth's upper atmosphere. These new effects serve to discriminate between various theories of terrestrial-magnetic changes and supply evidence on the electrical processes taking place in the ionosphere. The evidence yielded by the automatic recorders at the Huancayo and Watheroo observatories concerning the nature of the radio "fade-out" effect indicates that this phenomenon is predominantly due to an intense ionization between heights of about 60 and 100 km. The high ionization produced below the lower *E*-region of the ionosphere by bright chromospheric eruptions apparently causes radio-echo disappearance through absorption in this region of high collisional frequency. A definite magnetic effect is observed during the fade-out. Analysis of this effect shows it to be an augmentation of the magnetic diurnal variation as contrasted with other types of magnetic disturbance. The association of a magnetic effect of the diurnal-variation type with a definite region of the ionosphere through experimental observations forms a contribution of first importance to the science of terrestrial magnetism. The simultaneity of the fade-out, magnetic, and earth-current effects with solar outbursts in the region of sunspot-areas was confirmed by direct observation at the Huancayo Magnetic Observatory.

An aspect of correlation of terrestrial-magnetic with cosmic-ray phenomena was shown by the discovery, from cosmic-ray investigations at the Department, of the effect of a magnetic storm upon cosmic-ray intensities at widely separated stations. A study of changes in cosmic-ray intensity occurring at Huancayo and Cheltenham simultaneously with changes in magnetic horizontal-intensity during the magnetic storm beginning April 24, 1937, showed definitely for the first time that a magnetic storm can produce world-wide changes in cosmic-ray intensity. This effect may prove useful in furthering knowledge of the energy-distribution of cosmic rays and may provide valuable evidence regarding the location of the current-system responsible for magnetic storms. It may also point the way, in some known or unsuspected terrestrial-mag-

[1]For complete details of the work here summarized reference may be made to Year Book No. 36 for year 1936-37 of the Carnegie Institution of Washington (1937).

netic phenomena, to the cause for the solar-diurnal variation in cosmic-ray intensity.

The effect of the Moon on variations of the Earth's magnetism was demonstrated in the further discussion of the data accumulated at Huancayo from 1922 to 1934. The lunar influence there is so great that it actually may be noted in a single day's record.

Secular change of the Earth's magnetic field was studied further by comparing the data used by Ad. Schmidt and by Furner and Dyson for their analyses of the permanent field for the epochs 1885 and 1922. Charts were constructed showing the distribution of the vectors for the horizontal components of change and of isopors for the vertical component. Outstanding on the charts was a region of decreasing northern magnetic potential off the Guinea Coast where the change in the 37-year interval covered by the charts amounts to 6000 gammas—one-tenth of the value of the permanent field at the poles. It seems quite likely that secular change involves a change in the regions where the permanent field of the Earth originates. Attempts to express the secular change represented by the charts by a spherical harmonic series indicated absence of any relation between the relative values of the changes in the various harmonics and the intensity of those harmonics in the expression for the permanent field.

The final discussion of more than 2200 declination-values of the *Galilee* and the *Carnegie* in the Pacific was completed. In connection therewith large-scale isogonic charts of the North Pacific and of the South Pacific, and an isoporic chart of declination, all for the epoch 1920.0, were prepared.

Failure to account for the origin of the Earth's permanent magnetic field by any hypothesis consistent with the high temperatures usually assigned to the interior has led to an examination of the validity of the assumptions by which these temperatures are derived. During the year consideration was given to the possibility that the interior of the Earth might be considerably cooler than commonly thought and a hypothesis was proposed to account for the lower temperature at great depths, attributable to a different mode of cooling for the Earth, which may permit the interior to be ferromagnetic.

The possibility that the magnetization of rocks may yield interesting information regarding the history of the Earth's magnetic field in past geologic ages and may furnish rapid dating of various rock-samples led to experiments on electromagnetic measurements of rock-samples. In this connection, particular interest is attached to the magnetic properties of ocean-bottom samples obtained with the apparatus designed by Piggot of the Geophysical Laboratory of the Carnegie Institution of Washington. A method for measuring the magnetization of the specimens by rotating them in a coil connected to a tuned amplifier was attempted but the method has not yet been sufficiently developed to permit quantitative statements, although preliminary experiments promise success.

Investigation of the magnetic-disturbance field associated with magnetic bays and possible current-systems which might give rise to them was continued. A discussion was made of the field of magnetic storms as deduced from the mean difference of magnetic intensity on quiet and disturbed days. The current-system derived from the spherical harmonic analysis exhibits three regions of maximum intensity, near the equator and near the auroral zones.

To meet the need for an accurate and immediately available measure of magnetic disturbance, the Department, in collaboration with various governmental agencies and radio amateurs, began, March 13, 1937, to supply weekly bulletins on the state of the Earth's magnetic field for each Greenwich half day. These bulletins are based upon the estimates of the magnetic character-number supplied by the two observatories of the Department and the five observatories of the United States Coast and Geodetic Survey. This measure has been welcomed by both commercial and scientific organizations, and advance estimates of radio transmission-conditions based upon it already indicate its usefulness.

The design and construction of a new type of primary standard of high precision for measuring the magnetic vector of the Earth's magnetic field, begun last year, was continued. The instrument consists of a carefully constructed Helmholtz coil and a rotating-coil, alternating-current detector of the type previously developed and described. It is designed to measure the horizontal and vertical components of the magnetic vector and the declination, thus completely specifying the magnetic field at the point of measurement for the first time with a single instrument.

An automatic current-control was also developed which will find important applications to instrument recording. It permits registration of the magnetic elements by means of pen-and-ink recorders and was successfully applied to a leak-free method of recording potential-gradient.

Atmospheric electricity—Preparatory work was done to compile a great mass of data for obtaining evidence as to whether cycles longer than one day have a universal aspect. From a limited amount of material, some evidence has been found that, if the average of the electric field for a year is large or small at one place, it tends to be large or small, respectively, at other places, although they may be far apart. Such a conclusion, if established, is especially important for the bearing it may have on any solution offered for the fundamental problem of atmospheric electricity, namely, how does the Earth acquire and maintain the negative charge detectable on its surface wherever fair weather prevails?

Investigations bearing upon the fundamental problem of atmospheric electricity, the source of the charging current, were continued. At Watheroo, Huancayo, and Tucson, the field-strength and the electrical conductivity of the air were registered continuously.

Continuous records of the rate of formation of the fast-moving ions in the atmosphere have provided evidence pointing to the existence of an unsuspected factor in the atmosphere, tending to control its electric conductivity. This factor is the water-vapor in the atmosphere, which appears to combine with the large or slow-moving ions, thus making them more efficient in removing the small or fast-moving ions in the atmosphere. Another approach to this problem was obtained through H. L. Wright's formula relating the size of the large ion with the number of condensation-nuclei, charged and uncharged. Data taken in Washington in 1931 with the nuclei-counter and the large-ion counter, using Wright's formula, again show no correlation between size of the large ion and relative humidity, but do show a high correlation between size and absolute amount of water-vapor in the air. The result is in agreement with that obtained from the study of the combination-coefficient between small and large ions.

Continuous records with two similar thin-walled ionization-chambers

make possible study of the relative amounts of positively and negatively charged radioactive material in the air, the precision with which the rate of ionization is measured, the amount of ionization ascribable to alpha particles, beta particles, and gamma rays from radioactive material in the air and soil, and other valuable information. Thus far but little of this information has been secured. However, comparison was made of the rate of ionization inside the two thin-walled chambers, with different signs of potential on the outer electrodes. No appreciable difference in ionization could be noted whether the outside electrode was positively charged or was without charge. On the other hand, approximately four times as much ionization occurred inside the chamber having a negative charge on the outside as in the chamber with zero-charge. These experiments indicate that a large part of the radioactivity produced in the lower atmosphere is positively charged, thus supporting other results.

Study of the manner in which the coefficient of recombination of positive small ions varies with pressure, on the basis of data obtained on the stratosphere flight of the *Explorer II*, showed that if that coefficient varies not as a first power of pressure but nearly as the cube root of the pressure, then there would be no important disparity to attribute to nuclei in the large altitude-range from 6 to 18 km. Above and below these altitudes the disparity, now reduced; could be more acceptably regarded as due to nuclei.

In another attempt to explain the stratosphere measurements, the recombination-coefficient for small ions was taken to vary directly as the first power of the pressure while the coefficient of combination of small ions with large ions was taken to vary inversely as the pressure. According to the calculations made in this way, the number of nuclei required to account for the disparity between the calculated and the observed values of conductivity is not objectionally great and the distribution of nuclei with altitude for altitudes greater than three km is about the same as that calculated for very small spherical particles that are introduced into the high atmosphere at a uniform rate and fall at a rate given by the Stokes-Cunningham law. There is, however, another result of these considerations that is more difficult to accept, namely, the extreme effectiveness of nuclei in reducing the conductivity at the higher altitudes. Thus, at 18 km the presence of 85 nuclei in one cubic centimeter would reduce the conductivity 60 per cent and the effectiveness would increase at higher altitudes. These studies suggest problems for investigation in the future.

Equipment for use on aircraft to measure the electric field-strength was designed. The design is such that if the equipment is placed in certain positions of symmetry, relative to the electric field which may arise from electric charges developed on the craft, the measurements are then unaffected by that charge.

The cosmic-ray registrations obtained at Huancayo and Cheltenham were evaluated, and the barometer-effect, temperature-effects, and the diurnal variation were studied by means of a statistical analysis. A light-weight, short-wave radio-transmitter piloted by a Geiger counter, was devised and constructed. When carried aloft by a sounding-balloon, it sent out a signal whenever a cosmic-ray corpuscle passed through the counter; at intervals it also sent signals which gave a measure of the altitudes of the balloon. These were picked up and re-

corded on apparatus developed by and located at the National Bureau of Standards.

Geoelectricity –The earth-current records were examined for correlation between earth-current deflections and the bright solar eruptions accompanying radio fade-outs. Further attention was given also to the variation of the diurnal range in earth-currents during the sunspot-cycle. Ranges greater than any registered at the maximum of the last sunspot-cycle were reached at Huancayo early in 1937 and the records from Tucson show a steady increase in range since 1932.

The study of the variation in the daily mean values of earth-current potentials to determine the existence and magnitude of components in earth-current flow with periods longer than one day indicates part of the current flowing during disturbances to be unidirectional for the day. The magnitude of this "disturbance-component" is only a few per cent of the range of the diurnal variation and its direction at a given station is consistent with that noted in the diurnal-variation records.

Determination of the lunar diurnal-variation in earth-currents was begun. The method employed by Chapman for the magnetic elements, was applied to the Tucson records for 1932, near the minimum of sunspots. The data for this single year reveal a definite lunar diurnal-variation of markedly double period for both northward and eastward components. Harmonic analyses show that the amplitude of the second harmonic is about one-fifth of that found in the solar diurnal-variation for the same year, while the amplitudes calculated for the first, third, and fourth harmonics are all negligibly small. Portions of the data for the same year were also investigated for lunar diurnal-variation by the method applied by Egedal to the data from the Ebro Observatory. In this method the lunar diurnal-variation is obtained from the records for individual solar hours of the day. Comparison of the lunar diurnal-variation obtained separately by this method during daylight with that obtained during night hours, showed no decided difference in either amplitude or phase. The investigation so far made indicates that the general features of lunar diurnal-variation in earth-currents are determinable from a comparatively brief series of records at least when, as at Tucson, long lines are used.

Observations of electric gradients in the Earth made on Pass Mountain in the Shenandoah National Park, near Luray, Virginia, showed an apparent electrical gradient of fairly constant magnitude and direction all along the line from west to east. They do not support the conclusion reached by a number of observers that the electrical potential-gradient in mountainous regions is always directed from the base to the top of a mountain. The direction of flow indicated in these experiments was up the slope on the west side of Pass Mountain and downward on the east side. The results do indicate the possibility that large local circulations of current occur in such mountainous regions.

Ionospheric research Mathematical considerations have long pointed to an electrified upper atmosphere as the seat of magnetic disturbance and variation. With this in view, the Department initiated an experimental approach to problems of the outer atmosphere (the ionosphere) in 1925 when direct experimental evidence of ionized regions in the outer atmosphere was obtained. Subsequent experiments showed the distribution of this ionization to be complex. Advances in experimental technique have permitted formulation of more exact ideas as to the loca-

tion, nature, and characteristics of the ion-banks which exist there. The association of a particular region of the ionosphere with a magnetic effect of the diurnal-variation type as above noted therefore represents a definite advance toward the original objective of examination of theoretical concepts of these phenomena by experimental methods.

Continuance of the program of recording permitted formulation of more concrete ideas as to the variation of ionization in the outer atmosphere. A change with the sunspot-cycle is now becoming apparent. This change has been large—in fact, it appears that the relation of the ionospheric ionization to sunspot-number may be one of the closest solar and terrestrial relationships yet found.

With the completion of continuously recording equipment for determination of ionization throughout the ionosphere, further evidence as to the nature of the electrified particles in the various regions was obtained. A limiting value can now be placed on the ratio of electrons to ions of atomic or molecular size in the *E*-region (at about 100 km). This restriction aids greatly in determining the physical processes involved in the ionosphere and in the selection of proper theoretical ideas concerning terrestrial magnetism. The records from this new equipment have presented new, and heretofore unsuspected, problems in the study of the ionosphere—at the same time providing much experimental data for their solution.

Further study was directed toward the diurnal, seasonal, and long-time changes of ionization of the major regions, as well as unusual effects which have been observed. The increase of ionization of all regions with the advance of the sunspot-cycle was pronounced. Since the sunspot minimum in 1933-34, the increase in the mean noon value of ion-density in the *E*- and F_1-regions (heights of about 100 and 200 km, respectively) was more than 45 per cent, while in the F_2-region (above 280 km) it was more than 250 per cent. The continued investigation of the annual change of ionization in the F_2-region showed that the highest value of ion-density occurred during April at Watheroo as compared to February at Washington. A definite minimum in average values of F_2-region ion-density occurs at Washington, Huancayo, and Watheroo during July.

An analysis of the sporadic ionization of the *E*-region showed this effect apparent at Huancayo only about six hours out of some 8000 hours of observation. At Watheroo the effect is about 70 times as pronounced. The location of Huancayo on the magnetic equator relative to Watheroo far south of the magnetic equator suggests the possibility of magnetic control of this effect.

Records obtained with the completed multifrequency automatic recorder at the Kensington Experimental Station show the "o" and "x" wave-components from the *E*-region completely resolved. Measurements of the separation of the critical frequencies for these components show that reflection of the radio wave is primarily due to electrons. Using the method developed at the Department, the ratio of electrons to ions of atomic or molecular size must be greater than 10^3 for the observations to date at the level of maximum electron-density of the *E*-region. This determination bears directly upon the concepts of current-flow and diamagnetism in this region of the ionosphere.

Because of the world-wide aspects of ionospheric investigations, close cooperation has been maintained with observers throughout the world.

Following completion of the development of an automatic multi-frequency ionospheric recorder, reported last year, the construction of the first of these units for use at the observatories was completed in the instrument-shop during the year. This unit records continuously the virtual height of waves of frequencies between 0.516 and 16.0 mc sec during successive 15-minute intervals. Operation is continuous, 96 records of the virtual heights of equivalent electron-densities between 3000 and 3,000,000 per cubic centimeter being obtained each day. Thus rapid ionospheric changes can be followed in detail. Completion of this equipment represents introduction of one of the most promising and productive fields for ionospheric investigation so far devised. Operation during test has already shown certain characteristics of the ionosphere hitherto unsuspected.

Nuclear physics—Continuing the laboratory-investigations of magnetism, as relating to the basic structure and properties of matter, further measurements on the "new" physical force, which serves to bind together the protons and neutrons making up the nuclei of all atoms, confirmed and extended the first observations and measurements announced last year. This force has long been inferred to exist as a universal property of matter, ranking with gravitation and electromagnetic forces in its importance to the structure of the cosmos. Its direct observation and measurement last year using the Department's high-voltage equipment, now strikingly confirmed by the new measurements, is an achievement of lasting future importance. Other measurements in connection with these investigations, relating to neutron-intensities, appear separately important to biochemical, genetic, and cancer researches, and exemplify the wide significance and application of such fundamental studies. Precise measurements on the most familiar group of nuclear transmutations—those of lithium—demonstrated the existence of an unexpected four-body process, and give hope of a future experimental demonstration of the existence of the hypothetical particle called the neutrino, which has been assumed to exist because of certain crucial difficulties in the understanding of transmutation-processes involving electron (beta-ray) emission.

The construction of a long-planned Atomic-Physics Observatory, which will contain a generator and a vacuum-tube capable of reaching potentials in excess of 5,000,000 volts with precision control, was begun in May 1937. This equipment will greatly extend the possible scope of the Department's researches on the nature of magnetism and the basic structure of matter.

Magnetic survey—The Section of Land Magnetic Survey has maintained observation, collection, compilation, and discussion of data relative to the magnetic field of the whole Earth. Because of limited funds available for the survey, only a modest amount of field-work was done this year by the Department.

Arrangements were completed for cooperation in securing magnetic data in the arctic through the loan of instruments and the preparation of instructions and directions for the MacGregor Arctic Expedition of 1937-38 on the steamer *General A. W. Greely*, which left Newark, New Jersey, July 1, 1937.

The principal field-work was in Australasia and the Pacific Islands, in continuation of the extensive program inaugurated early in 1936. Using Sydney, New South Wales, as a base, five expeditions were completed in the course of which 53 stations were occupied. In Asia seven

stations were occupied—one in China, four in Arabia, and two in Iraq. Instrumental comparisons were carried out at the Apia and Honolulu observatories, as well as at the Zosé Observatory in China. Many comparisons of instruments and determinations of their corrections on the International Magnetic Standards of the Department were made at the Cheltenham Magnetic Observatory of the United States Coast and Geodetic Survey.

Observatory-work—At Watheroo and Huancayo observatories continuous records were obtained of the three magnetic elements, of atmospheric potential-gradient, of positive and negative conductivity of the atmosphere, of earth-currents, of heights of the ionosphere using a fixed frequency, and of the meteorological elements. At the Huancayo Observatory there were also obtained continuous records with a three-component seismograph and a precision cosmic-ray meter as well as daily spectroheliosopic observations during the assigned two half-hour periods; comparison records of the cosmic-ray meter were obtained for 37 days, May to June, 1937, with a portable Millikan-Neher cosmic-ray meter. The cooperative work in atmospheric electricity was continued with the Apia Observatory of the Department of Scientific and Industrial Research of New Zealand. At Tucson, in cooperation with the United States Coast and Geodetic Survey, the program was continued in the atmospheric-electric and earth-current fields, the latter with the additional cooperation of the Bell Telephone Laboratories. At Cheltenham the United States Coast and Geodetic Survey operated the CIW vertical-intensity induction-variometer during the year. The operation of the CIW sine-galvanometer maintained both the Department's and the Survey's standards in horizontal intensity. Good progress was made toward full realization of the ionospheric program in cooperation with the University of Alaska at College, Alaska. The final report on auroral observations at College during 1930 to 1934 was issued as Volume III of "Miscellaneous publications" of the University.

The magnetic observations for the year 1935 from the Watheroo and Huancayo observatories were reduced and preliminary reductions for the year 1936 were made. The manuscript tabulations of the Watheroo magnetic data for 1921 to 1934 were revised to correct for the contribution of variation in declination to the observed variations in horizontal intensity arising because the magnet in the Eschenhagen horizontal-intensity variometer was placed 6°.5 out of magnetic prime-vertical in 1921. The final revision of the manuscript of Watheroo results for 1919 to 1934 is now complete.

Oceanographic reductions—The final revisions of the manuscripts, graphs, and maps giving the oceanographic data secured during the last cruise of the *Carnegie* and of discussions based thereon were completed for the first two volumes of the proposed series "Results of oceanographic and meteorological work obtained on board the *Carnegie*, Cruise VII, 1928-1929, under the command of J. P. Ault." Final revisions of manuscript and added discussion on the meteorological results were begun; this material will form Volume IV of the series. Volumes III and V will contain biological results.

Miscellaneous work—The cooperation with other investigators and organizations engaged in work similar to that of the Department has been continued in accordance with the policy consistently followed in the past.

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C.

PROVISIONAL SUNSPOT-NUMBERS FOR SEPTEMBER AND OCTOBER, 1937

(Dependent alone on observation at Zürich Observatory and its station at Arosa)

Day	September	October
1	109	131
2	110[a]	*W*170[c]
3	127[d]	214[abd]
4	82	206[b]
5	*E*79[c]	...
6	*M*85[ac]	*E*172[ac]
7	*E*101[cd]	...[a]
8	104	...
9	119[a]	*EEW*153[accc]
10	...[a]	161[a]
11	...[a]	*E*148[acdd]
12	101[d]	137[a]
13	110	142
14	101	*E*131[c]
15	99	113[d]
16	76	127[a]
17	58[d]	127[ab]
18	*M*82[ac]	121
19	*M*88[c]	114[a]
20	88[a]	*E* 89[c]
21	73	72[a]
22	*W*...[cd]	58
23	...	*W* 63[c]
24	120[a]	*E* 76[cd]
25	*E*127[c]	69
26	74	56[b]
27	80	58
28	101[ad]	*E*104[c]
29	126[aa]	90[ad]
30	121[d]	*E*113[c]
31		133[a]
Means....	97.7	119.6
No. days..	26	28

Mean for quarter July to September, 1937: 128.0 (85 days)

[a]Passage of an average-sized group through the central meridian.
[b]Passage of a large group or spot through the central meridian.
[c]New formation of a group developing into a middle-sized or large center of activity: *E*, on the eastern part of the Sun's disc; *W*, on the western part; *M*, in the central-circle zone.
[d]Entrance of a large or average-sized center of activity on the east limb.

EIDGEN STERNWARTE,
Zürich, Switzerland

W. BRUNNER

PROGRESS OF MAGNETIC SURVEY IN THE UNION OF SOUTH AFRICA

At the request of the International Commission for the Polar Year 1932-33, Dr. A. Ogg, Professor of Physics at the University of Cape Town, established in August, 1932, a Magnetic Observatory at Cape Town. The Observatory had to be built near the Physics Department of the University, although it was realized that the suburban electric railways would have a disturbing influence. As the work of the Observatory had to be controlled by the staff of the Physics Department there was no alternative. Grants from the Department of the Interior made it possible to continue the Observatory from April, 1934, to April, 1937, with B. Gotsman as Observer.

To secure the permanency of the Observatory, the University of Cape Town appointed Professor Ogg, on his retirement from the Chair of Physics in July, 1936, Director of the Observatory and cooperated with him in negotiating with the Director of the Trigonometrical Survey Office of the Union of South Africa for the transfer of the Observatory to that Department.

The Government, on the recommendation of the Director of the Trigonometrical Survey Office, has established from April 1, 1937, a Magnetic Branch of the Trigonometrical Survey Office, with Dr. Ogg as Magnetic Adviser, B. Gotsman, M.Sc. as Assistant, and K. Simpson, B.Sc., for field-work. The program contemplates first of all the building of a new observatory and the establishment of secular-variation stations throughout the Union of South Africa.

The establishment of this magnetic service is due to the assistance, financial and otherwise, of the Carnegie Corporation, New York; the Department of Terrestrial Magnetism, Carnegie Institution, Washington; the University of Cape Town; the International Commission for the Polar Year 1932-33, and the Department of the Interior of the Union of South Africa.

Capetown, Union of South Africa A. OGG

AVERAGES OF CRITICAL FREQUENCIES AND VIRTUAL HEIGHTS OF THE IONOSPHERE, OBSERVED BY THE NATIONAL BUREAU OF STANDARDS, WASHINGTON, D. C., SEPTEMBER AND OCTOBER, 1937[1]

The following ionosphere data are in continuation of those published for 1934-36 in this JOURNAL.[2] The symbols used are:

h_E = E-region virtual height, kilometers (lowest measured height)

h_{F_1} = F_1-region virtual height, kilometers (lowest measured height)

h_{F_2} = F_2-region virtual height, kilometers (lowest measured height)

f_E = E-region critical frequency, kilocycles per second, ordinary ray

$f^o_{F_1}$ = F_1-region critical frequency, kilocycles per second, ordinary ray

$f^x_{F_2}$ = F_2-region critical frequency, kilocycles per second, extraordinary ray

EST = Eastern standard time (75° west meridian time); add 5 hours for Greenwich time

♯ = Manual measurements

* = Less than ten measurements with automatic recorder

TABLE 1—*Ionosphere data, National Bureau of Standards, Washington, D. C.*

h_E	h_{F_1}	h_{F_2}	f_E	$f^\circ_{F_1}$	$f^x_{F_2}$	h_E	h_{F_1}	h_{F_2}	f_E	$f^\circ_{F_1}$	$f^x_{F_2}$
		September, 1937[a]						*October, 1937*[a]			
		300			7690			297			7370
		299			7440			301			6955
		296			7090			305			6560
		298			6700			310			6160
..		300	800#		6260			318			5760
...		280#	730#		5960	116#		315	1100#		5600
...		260#	1790#		7075	110#		285	1440#		6280
125	242	252#	2620		8855	120#		247	2340#		8800#
122	235	252#	3160		10240#	122		238	2890		11270#
121	232	252#	3490		11150#	120	231	239#	3246		12020#
119	227	266#	3703		11560#	119	226	241#	3445		12760#
120	226	272#	3817		11700#	117	226	242#	3587		13450#
120	224	286#	3880		11680#	118	233	249#	3643		13800#
118	234	290#	3810		11680#	119	236	251#	3610		13920#
120	239	296#	3659		11780#	120	240	247#	3463		13960#
121	241	290#	3440		11780#	120	241	247#	3208		13830#
125	242	286#	3090		11660#	120	245	250#	2860		13320#
126	249	266#	2610		11480#			243	2250#		12860#
.		247	2000#		11300#			238	1250#		11850#
..		249	1200#		10260#			245			10433
		258			9060			257			9160
		271			8550			270			8600
		290			8100			276			8118
		296			7880			287			7711

[a]F_1 critical frequencies not well defined during September.
[1]Communicated by the director of the National Bureau of Standards of the United States Department of Commerce.
[2]T. R. Gilliland, S. S. Kirby, N. Smith, and S. E. Reymer, Terr. Mag., **41**, 379-388 (1936).

NATIONAL BUREAU OF STANDARDS,
UNITED STATES DEPARTMENT OF COMMERCE,
Washington, D. C.

PROVISIONAL SOLAR AND MAGNETIC CHARACTER-FIGURES, MOUNT WILSON OBSERVATORY JULY, AUGUST, AND SEPTEMBER, 1937

Greenwich mean time						Range Hor. int.
Beginning			Ending			
1937	*h*	*m*	*d*	*h*	*m*	γ
July 19	12	54*	20	13	..	114
Aug. 1	21	50*	2	20	..	186
Aug. 22	3	08*	22	14	..	222
Sept. 10	17	50	11	16	..	143
Sept. 30	13	45*	Oct. 1	24	..	156

Although the Sun was extremely active in the third quarter of 1937, especially in July and August, only five magnetic storms occurred.

An active area including four sunspot-groups crossed the central

*Sudden commencement

July 1937

Day	K_2 A	K_2 B	$H\alpha B$ A	$H\alpha B$ B	$H\alpha D$ A	$H\alpha D$ B	No. groups	Mag'c char.
1	3	3	3	3	3	2	6[g]	0
2	3	3	3	3[c]	3	2	9[b]	0
3	3	3	...	...[c]	...	...	6[b]	...
4	...	...	3	3	4	2	9	0
5	...	...	3	3	4	1	8[h]	0.5
6	3	3	3	3[c]	3	2	11	1
7	3	3	3	3[c]	3	2	11[f]	...
8	4	4	3	3[c]	4	3	16[b]	0
9	...	...	4[d]	3	4	3	18[h]	1
10	4	4	4[d]	3	3	2	21	0.5
11	5	4	5[d]	4	3	2	23	0.5
12	5	5	5	5[c]	4	3	21[f]	0
13	5	5	5	5	3	2	23	0
14	5	5	5[d]	5	4	3	22[a]	1
15	5	5	5	5	4	3	22	0.5
16	5	4	5[d]	4	4	3	16	0
17	5	4	5	4	3	2	17	0.5
18	4	4	4	4	3	2	18[f]	0.5
19	4	4	4[d]	4	3	2	16[f]	1
20	4	4	4[d]	4[c]	3	3	15[b]	1
21	4	4	...[d]	...	...	...	13	0.5
22	5	4	5	4	3	2	13	1
23	5	4	5	4	3	3	11[h]	1
24	5	4	5[d]	4	4	4	9	1
25	5	4	5[d]	4	4	3	8	0.5
26	...	...	...[d]	...	...	...	8	0.5
27			4[d]	4	3	1	9	...
28			4	4	3	1	9?	0
29		...	...	...	...	...	9	...
30	...	...	...	...	...	...	...	0.5
31	4	3	5[d]	3	3	2	10	0
Mean	4.3	3.9	4.2	3.8	3.4	2.3	13.6	0.5

August 1937

Day	K_2 A	K_2 B	$H\alpha B$ A	$H\alpha B$ B	$H\alpha D$ A	$H\alpha D$ B	No. groups	Mag'c char.
1	4	4	4[d]	3	3	3	12	0.5
2	5	4	4[d]	4	3	2	12	1.5
3	5	4	...	...	...	...	17[a]	0.5
4	...	...	5	4	3	2	18	1
5	...	...	...	...	...	...	13[h]	0
6	5	4	5	4	3	3	13	0.5
7	5	4	5[d]	4	3	4	13	0
8	5	4	5[d]	4	4	5	16	0
9	5	5	5	4	3	3	18	0
10	5	4	5[d]	4	3	3	19[h]	0
11	5	4	5	4	4	2	14	0
12	5	4	5	4	3	3	15	0
13	5	4	5	4[c]	3	2	9	0
14	5	5	5[d]	5	3	2	10[f, i]	0.5
15	5	4	5	4[c]	3	2	9	0.5
16	5	3	5	3[c]	4	2	9	0
17	5	3	4	3	4	3	8	0
18	4	4	4	4	4	3	6	0
19	4	4	4	3	4	3	9[b]	0
20	4	3	...	...	...	...	10	0
21	4	2	4	2	3	3	8	0
22	4	2	4[d]	3	3	1	11	2
23	4	3	4	3	3	1	11[k]	0
24	5	5	4	4	3	1	11	0
25	5	5	5	5	2	1	12[i]	0
26	...	...	5	4	3	2	11	0.5
27	5	4	5	4	3	2	13	0.5
28	...	...	5[d]	4	3	2	12	0
29	5	3	5[d]	3	4	3	12	0.5
30	4	3	4	3	4	3	10	0
31	5	4	4	3	4	3	11	0
Mean	4.7	3.8	4.6	3.7	3.3	2.5	12.0	0.3

September 1937

Day	K_2 A	K_2 B	$H\alpha B$ A	$H\alpha B$ B	$H\alpha D$ A	$H\alpha D$ B	No. groups	Mag'c char.
1	5	3	4	3	4	4	10	0.5
2	...	...	5	4	4	4	8	0
3	5	4	...	...	...	...	9[i]	0
4	5	4	5	4	3	1	7	0.5
5	5	4	5	4	4	3	5	0
6	5	4	5	4	4	3	7	0
7	5	4	5	4[c]	4	4	7[b]	0
8	5	4	5[d]	4	4	2	6	0
9	...	...	4	4	4	2	6[e]	0
10	4	4	4	4[c]	3	3	7	0.5
11	4	5	4[d]	4	3	3	7[e]	1
12	4	4	4	4[c]	3	2	8	0
13	4	3	4	3	2	3	7	0.5
14	4	3	4[d]	3	3	3	8	0.5
15	4	2	3	2	2	2	9	0.5
16	3	2	3	3	2	2	9	0.5
17	4	3	4[d]	3	2	1	10	0.5
18	4	4	4	4	2	0	11[a]	0.5
19	4	4	4	3	2	1	9	0
20	4	4	...	...	...	...	9	0.5
21	3	3	...	...	...	...	11[a]	0
22	4	3	4	3	3	2	13	0
23	4	3	4	3	3	2	12	0
24	5	4	5	4	3	2	14	0.5
25	4	4	4	4	3	2	11[b]	0
26	5	4	4[d]	4	3	2	11	0
27	4	4	5[d]	4	3	3	10	0
28	5	4	4	4	3	2	11	0
29	5	4	5[d]	4	3	1	10	0
30	4	4	4[d]	3	4	1	11	1
31								
Mean	4.3	3.6	4.3	3.6	3.1	2.2	9.1	0.2

Note—For an explanation of these tables see this Journal, 35, 47-49 (1930). The character-figures of solar phenomena are estimated from the spectroheliograms which are made with a 2-inch solar image, usually in the early morning. The very bright chromospheric eruptions are reported in these notes if observed at any time during the day.

?Indicates an uncertain value which should be given low weight.

... to average size or larger: (a) less than 30° from the center of the disc, (b) more than 30° from the center of the disc.

meridian from July 18.5 to July 20.0, GMT. At the beginning of the storm of July 19 the largest and most active of these was 24 hours past the central meridian.

The storm of August 1 occurred when a very large active group, the largest since January 1926, was four days west of the central meridian, and another active area including two groups was four days east. Twenty days later, another storm occurred which may also have been due to the very large active group which by that time had returned, diminished in size, and was three days east of the central meridian when the storm began.

When the storm of September 10 began several active groups were near the central meridian, one approaching it and another one day past, both passing within 5° of the center of the disc.

A very large active group was four days east of the central meridian when the storm of September 30 began.

CARNEGIE INSTITUTION OF WASHINGTON,
MOUNT WILSON OBSERVATORY, SETH B. NICHOLSON
Pasadena, California ELIZABETH E. STERNBERG MULDERS

AMERICAN *URSI* BROADCASTS OF COSMIC DATA[1], JULY TO SEPTEMBER, 1937, WITH AMERICAN MAGNETIC CHARACTER-FIGURE C_A, SEPTEMBER TO NOVEMBER, 1937

The data for terrestrial magnetism, sunspots, and solar constant are the same as given in previous tables.

The first three columns of the Table give (1) the magnetic character according to the scale 0-2 of the International Commission of Terrestrial Magnetism and Atmospheric Electricity, (2) the type featuring the day other than normal by the letters *b*, *p*, *o*, and *i* for days marked by bay, rapid pulsations, long-period oscillations, and irregular oscillations, respectively, and (3) the hour and minute of Greenwich mean time marking the beginning of a storm, the end of the storm being indicated in the foot-note to the Table. The next two columns give the data relating to sunspots: (1) the number of groups of spots and (2) the total number of spots. It is to be noted that sunspot-numbers such as those from Zürich can be obtained from the number of groups and spots given in the Table by the formula $N = k\ (10g+s)$, where the mean value of k for Mount Wilson was 0.53 during 1936.

Mount Wilson Observatory is now supplying corrections and additions to the sunspot-data which are broadcast in the *URSI*gram. So far as possible, these additional and corrected values will be used in this tabular summary and will be designated as such in foot-notes to the Table.

Beginning January 1, 1934, the magnetic information of the *URSI*gram is for Cheltenham, Maryland, instead of Tucson, Arizona. In addition to this change in observatory, the data cover the 24 hours ending 8 A. M., 75° west meridian mean time, instead of the 24 hours ending at 7 A. M., 105° west meridian mean time.

In accordance with information received from Dr. C. G. Abbot, Secretary of the Smithsonian Institution on March 6, 1937, solar-constant values were discontinued owing to important change in methods.

The data for the table of Kennelly-Heaviside Layer heights which is self-explanatory are supplied by the National Bureau of Standards.

[1]For previous announcements see Terr. Mag., **35**, 184-185 and 252-253 (1930); **36**, 54, 141, 258-259, and 358-360 (1931); **37**, 85-89, 189-192, 408-411, and 484-487 (1932), **38**, 60-63, 148-151, 262-265, 335-339 (1933); **39**, 73-77, 159-163, 244-247, 353-356 (1934); **40**, 111-115, 220-222, 334-336, 449-452 (1935), **41**, 85-87, 207-209, 315-317, 407-409 (1936); **42**, 89-91, 207-209, and 316-319 (1937).

Summary American URSI daily broadcasts of cosmic data, July to September, 1937

Greenwich date	July					August					September				
	Magnetism			Sunspot		Magnetism			Sunspot		Magnetism			Sunspot	
	Character	Type	GMT beginning disturbance	Groups	Number	Character	Type	GMT beginning disturbance	Groups	Number	Character	Type	GMT beginning disturbance	Groups	Number
			h m					h m					h m		
1	0	...	.. ..	6	90	0	*i*	21 50	12	220	0	...	.. ..	10*	180
2	0	...	.. ..	9	95	2	*i*	.. ..	12	265	0	...	.. ..	8	130
3	0	...	.. ..	6	50	1	*i*	14 30	17	280	0	...	.. ..	9	100
4	0	...	.. ..	9	65	1	*i*	.. ..	18	285	0	...	.. ..	7	120
5	0	...	.. ..	8	95	0	...	.. ..	...	...	0	...	.. ..	5	105
6	0	...	.. ..	11	115	0	...	.. ..	13	210	0	...	.. ..	7	120
7	1	*i*	.. ..	11	140	0	...	.. ..	13	155	0	...	.. ..	7	100
8	0	...	.. ..	16	170	0	...	.. ..	16*	185	0	...	.. ..	6	120
9	0	*i*	14 10	18	145	0	...	.. ..	18*	180	0	...	.. ..	6	180
10	1	*i*	.. ..	21	220	0	...	.. ..	19	190	0	*i*	17 50	7	175
11	0	...	.. ..	23	220	0	...	.. ..	14*	185	1	*i*	.. ..	7	195
12	0	...	.. ..	21	215	0	...	.. ..	15	165	0	...	.. ..	8	200
13	0	...	.. ..	23	210	0	...	.. ..	9	100	0	*b*	06 45	7	185
14	1	...	.. ..	22*	215	0	...	.. ..	10	185	0	...	.. ..	8	130
15	0	...	.. ..	22	200	0	...	.. ..	9	175	0	...	.. ..	9	110
16	0	...	.. ..	16	170	0	...	.. ..	9	145	0	*b*	07 10	9	70
17	0	...	.. ..	17	155	0	...	.. ..	8	130	0	...	.. ..	10	65
18	0	...	.. ..	18	185	0	...	.. ..	6	80	0	...	.. ..	11	70
19	0	*p*	13 00	16	165	0	...	.. ..	9	105	0	...	.. ..	9	80
20	1	*p*	.. ..	15	160	0	...	.. ..	10	110	0	...	.. ..	9	90
21	1	*i*	19 06	13	145	0	...	.. ..	8	110	0	...	.. ..	11	65
22	1	*i*	.. ..	13	200	2	*i*	03 08	11	135	0	...	.. ..	13	130
23	1	*i*	23 00	11	165	2	...	.. ..	11	180	0	...	.. ..	12	115
24	1	*i*	17 30	9	165	0	...	.. ..	11	195	0	...	.. ..	14	105
25	1	*i*	.. ..	8	200	0	...	.. ..	12	185	0	...	.. ..	11	100
26	1	*i*	.. ..	8	185	0	...	.. ..	11	255	0	...	.. ..	11*	70
27	0	...	.. ..	9	195	0	*b*	04 30	13	200	0	...	.. ..	10	70
28	0	...	.. ..	9	215	0	...	.. ..	12	180	0	*b*	18 00	11	70
29	0	...	.. ..	9	155	0	...	.. ..	12	170	0	...	.. ..	10	85
30	0	...	.. ..	...	...	0	...	.. ..	10	155	0	*i*	13 35	11	165
31	0	...	.. ..	10	215	0	...	.. ..	11	190					
Mean	0.3	...	.. ..	14	164	0.3	...	.. ..	12	177	0.0	...	.. ..	9	117

*Revision of value originally broadcast.

Greenwich mean time for ending of storms: 5^h, July 10; 8^h, July 21; 11^h, July 22; 7^h, July 24; 5^h, July 25; 10^h, August 2; 10^h, August 4; 14^h, August 22; 13^h, September 11; 24^h, October 1.

As set forth in this Journal for June, 1937, "The Department of Terrestrial Magnetism and United States Coast and Geodetic Survey with the cooperation of the United States Army and United States Navy communication-services and several amateur radio stations have undertaken to supply an American character-figure based upon the reports of the seven American-operated observatories—those of the Department of Terrestrial Magnetism at Huancayo in Peru and at Watheroo in

Kennelly-Heaviside Layer heights, Washington, D. C., July to September, 1937
(Nearest hour, Greenwich mean time, of all observations is 17)

Date	Freq.	Ht.	Date	Freq.	Ht.	Date	Freq.	Ht.	Date	Freq.	Ht.
1937	*kc/sec*	*km*	*1937*	*kc/sec*	*km*	*1937*	*kc/sec*	*km*	*1937*	*kc/sec*	*km*
July 7	2,500	120	July 28	9,000	640	Aug. 25	4,050	*	Sep. 15	2,500	120
" "	3,800	130	" "	9,200	*	" "	4,090	240	" "	3,500	140
" "	4,100	140	Aug. 4	2,500	120	" "	4,400	200	" "	3,600	*
" "	4,120	*	" "	3,500	130	" "	4,600	200	" "	3,800	*
" "	4,150	260	" "	4,100	180	" "	5,000	280	" "	3,900	250
" "	4,500	210	" "	4,150	*	" "	5,400	270	" "	4,200	230
" "	4,800	280	" "	4,200	180	" "	6,200	280	" "	5,400	270
" "	5,000	310	" "	4,400	140	" "	7,000	340	" "	6,200	280
" "	5,200	900	" "	4,600	210	" "	7,800	350	" "	7,000	300
" "	5,300	700	" "	5,200	250	" "	7,800	370	" "	7,800	300
" "	5,400	530	" "	5,400	530	" "	8,600	370	" "	8,600	320
" "	5,500	560	" "	5,600	610	" "	8,600	420	" "	8,600	340
" "	5,700	640	" "	5,800	570	" "	9,200	410	" "	9,400	340
" "	5,800	*	" "	6,200	710	" "	9,200	570	" "	9,400	380
" 14	2,500	120	" "	6,400	650	" "	10,000	550	" "	10,200	370
" "	4,000	150	" "	6,600	650	" "	10,200	*	" "	10,200	440
" "	4,120	220	" "	7,000	880	Sep. 1	2,500	120	" "	11,000	390
" "	4,200	*	" "	7,200	*	" "	3,500	130	" "	11,000	570
" "	4,500	210	" 11	2,500	120	" "	4,100	160	" "	11,600	480
" "	4,600	200	" "	3,500	140	" "	4,110	*	" "	11,800	*
" "	4,700	230	" "	4,200	150	" "	4,120	240	" 22	2,500	130
" "	5,000	280	" "	4,250	*	" "	4,400	210	" "	3,500	160
" "	5,200	340	" "	4,300	250	" "	4,600	220	" "	3,650	180
" "	5,400	440	" "	4,600	220	" "	5,400	300	" "	3,800	*
" "	5,500	*	" "	5,600	320	" "	6,200	340	" "	3,860	260
" "	5,800	810	" "	6,200	320	" "	7,000	340	" "	4,400	230
" "	5,900	*	" "	7,000	320	" "	7,800	360	" "	5,400	260
" 21	2,500	110	" "	7,800	390	" "	7,800	400	" "	7,400	280
" "	4,400	120	" "	7,800	410	" "	8,600	400	" "	9,000	300
" "	4,800	250	" "	8,800	450	" "	8,600	430	" "	9,800	330
" "	5,200	320	" "	8,800	570	" "	9,400	450	" "	9,800	350
" "	5,400	330	" "	9,600	550	" "	9,400	610	" "	11,000	370
" "	5,600	420	" "	9,800	*	" "	10,200	570	" "	11,000	420
" "	6,000	400	" 18	2,500	120	" "	10,400	*	" "	11,800	430
" "	6,800	410	" "	3,500	130	" 8	2,500	120	" "	11,800	630
" "	7,600	120	" "	3,980	140	" "	3,500	140	" "	12,220	480
" "	7,600	440	" "	4,000	180	" "	3,800	160	" "	12,260	600
" "	8,000	440	" "	4,400	130	" "	3,900	*	" "	12,280	*
" "	8,000	600	" "	4,400	240	" "	3,950	270	" 29	2,500	120
" "	8,600	540	" "	4,800	260	" "	4,400	230	" "	3,600	150
" "	8,800	*	" "	5,200	280	" "	4,600	240	" "	3,700	*
" 28	2,500	120	" "	5,400	300	" "	5,000	260	" "	3,900	280
" "	4,100	150	" "	5,400	360	" "	5,400	280	" "	4,400	250
" "	4,200	*	" "	5,800	330	" "	5,800	300	" "	4,600	230
" "	4,600	200	" "	7,000	340	" "	7,000	300	" "	5,400	270
" "	5,200	350	" "	7,800	360	" "	8,600	330	" "	7,800	280
" "	5,400	*	" "	7,800	390	" "	8,600	350	" "	9,400	320
" "	6,200	340	" "	8,600	400	" "	9,400	350	" "	11,000	370
" "	7,000	380	" "	8,600	640	" "	9,400	410	" "	11,000	430
" "	7,800	420	" "	9,400	700	" "	10,200	410	" "	11,600	400
" "	7,800	480	" "	9,600	*	" "	10,200	650	" "	11,600	530
" "	8,000	400	" 25	2,500	120	" "	11,000	700	" "	12,400	520
" "	8,000	530	" "	3,900	140	" "	11,200	*	" "	12,600	*

* = No value obtained.

American magnetic character-figure C_A for Greenwich half-days based on reports from Cheltenham, Honolulu, Huancayo, San Juan, Sitka, Tucson, and Watheroo for September and October, 1937

Day	September		October	
	0^h-12^h	12^h-24^h	0^h-12^h	12^h-24^h
1	0.1	0.6	1.2	0.9
2	0.1	0.1	0.2	0.0
3	0.1	0.1	0.2	1.0
4	0.4	0.1	1.9	0.9
5	0.4	0.1	0.1	0.5
6	0.0	0.1	0.4	0.6
7	0.1	0.3	0.9	1.0
8	0.1	0.1	1.4	0.8
9	0.0	0.1	0.7	1.6
10	0.1	1.1	1.5	0.8
11	1.4	0.5	0.8	1.5
12	0.0	0.0	0.8	1.0
13	0.4	0.4	0.4	0.1
14	0.8	0.5	0.4	0.3
15	0.4	0.2	0.9	0.7
16	0.5	0.4	0.1	0.2
17	0.4	0.4	0.0	0.1
18	0.2	0.5	0.2	0.2
19	0.1	0.1	0.1	0.1
20	0.0	0.1	0.0	0.1
21	0.4	0.0	0.1	0.3
22	0.1	0.4	0.2	0.7
23	0.1	0.2	0.6	1.2
24	0.6	0.1	1.1	1.1
25	0.0	0.1	0.4	0.5
26	0.1	0.2	1.0	0.9
27	0.1	0.1	0.8	0.7
28	0.1	0.1	0.5	0.6
29	0.0	0.1	0.1	0.3
30	0.0	1.6	0.0	0.0
31			0.1	0.0
Means	0.2	0.3	0.5	0.6
	0.2		0.6	

H. F. JOHNSTON

DEPARTMENT OF TERRESTRIAL MAGNETISM,
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Western Australia, and those of the United States Coast and Geodetic Survey at Cheltenham (Maryland), Honolulu (Hawaii), San Juan (Puerto Rico), Sitka (Alaska), and Tucson (Arizona)." This character-figure is being designated C_A, and the values for September to November, 1937, are given in the accompanying Table.

Errata—In the tables on pages 207 and 317 of this JOURNAL for 1937, the following table gives the revised Greenwich mean times of the beginning and ending of magnetic disturbances. The types of disturbance should read: January 8, *i*; January 9, *i*; and March 30, *b*.

January					February					March				
G. M. T. disturbance					G. M. T. disturbance					G. M. T. disturbance				
Beginning			Ending		Beginning			Ending		Beginning			Ending	
d	*h*	*m*	*d*	*h*	*d*	*h*	*m*	*d*	*h*	*d*	*h*	*m*	*d*	*h*
7	19	20	8	01	2	23	05	4	04	1	13	20	2	13
9	5	00			14	23	25			4	23	00	6	03
12	14	00	13	13	18	19	05	20	13	14	16	00	15	07
27	8	38	28	07						21	17	00	23	13
30	15	12	31	00						26	20	56	28	11
April					May					June				
2	00	00	4	10	4	16	50	5	17	5	18	00	7	02
17	17	40	18	07	24	19	00	25	13	10	05	06	10	09
25	15	48	26	08	27	18	40	30	13	13	08	42	13	15
26	17	40	27	05						20	17	50	21	06
28	18	50	28	24						22	13	00	22	24

NOTE ON BORIS WEINBERG'S SUGGESTED MAGNETIC NOMENCLATURE

With regard to Dr. Weinberg's suggestion in this JOURNAL (**42**, 214, 1937) I believe that it is unnecessary to change the term *isopors* of *D*, *I*, *H*, and *Z* to isallogons, isallolines, isallo-*H*-dynams, and isallo-*Z*-dynams. My proposal is to adopt in addition the term "isallopors" of *D*, *I*, *H*, and *Z*—to designate the lines of equal second differences of an element in time (change in secular variation, change in annual change). Studies of these second differences may be very important and it seems possible now in some cases to construct isalloporic charts. For instance, the data and isoporic maps of *D* of the United States of America constructed by D. L. Hazard (Trans. Amer. Geophys. Union, 11th Annual Meeting, 206-214, 1930) and others furnish material for the construction of isalloporic maps. An interesting compilation of isoporic maps for many periods is afforded by N. H. Heck's article "Secular change in the magnetic elements in the United States" (C.-R. Assemblée Lisbonne 1933, Union Géod. Géophys. Internat., Ass. Mag. Electr. Terr., Bull. No. 9, Copenhague, 263-275, 1934). It would also be possible to draw a world isalloporic map—at present we have only the excellent isoporic maps of H. W. Fisk.

UNIVERSITY OF RIGA, LATVIA, L. SLAUCITAJS
September 23, 1937

NOTE ON AURORAS SEEN ON JULY 22, AUGUST 3 AND 4, 1937, IN SOUTHWESTERN NEW HAMPSHIRE

A report of auroras seen from a place about eight miles south-southwest of Keene, New Hampshire, has been received from E. M Brooks. The report is briefly summarized as follows:

July 22—A few isolated beams were seen running upwards from a faint band extending from the north to the northwest at $3^h\ 45^m$ GMT. No indication of the aurora remained after $4^h\ 15^m$.

August 3—A band was seen about five degrees above the northern horizon which extended to the northeast horizon. The observation was made at $4^h\ 30^m$, the aurora being obscured by a fog shortly afterwards.

August 4—At $2^h\ 30^m$ a spectacular bright beam extended upwards and to the right to a height of about 45° in the eastern sky. It was remarkably sharp in outline, being more distinct than the Milky Way which it crossed at one time, extending south of the zenith. At $3^h\ 30^m$ the aurora consisted of a broad area of light across the whole northern sky sufficiently bright to obscure stars in the vicinity.

The aurora of August 4 was also reported by Dr. C. F. Brooks at the Blue Hill Meteorological Observatory where it was first seen at $1^h\ 40^m$ GMT. The American magnetic character-figure for the periods from 0^h to 12^h on the above-mentioned dates were 1.1, 0.4, and 1.0, indicating that the phenomena were not associated with strong magnetic disturbance. Quite sharp variations in vertical intensity were recorded at the Cheltenham Magnetic Observatory during the display on August 4.

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A. G. McNISH

AURORAS OF SEPTEMBER 4 AND 10, 1937

Douglas F. Manning of Alexandria Bay, New York, reported: "We had quite an active display of the aurora last night, September 4, 1937, around 9 p. m., Eastern Standard Time. A low greenish glow with sharply defined rays." A later phase was observed at Lynn, Massachusetts, by Mrs. Anna P. Ricker, who, in a letter dated September 10, 1937, makes the following statement: "I was awakened about 3 a. m., September 5, 1937, and went to my window and saw these two great balls of fire about three feet in circumference to the naked eye and very close together; from each one several rays of light shot upwards, and these appeared three times in succession and from then on great waves of light at short intervals in a circular motion. These waves were about three or four feet wide and twice as long and in perfect dimension. The sky was of a decidedly pinkish color. . . ."

On the evening of September 10, 1937, at Silver Lake, New Hampshire, my son Edward and I observed a pronounced display which first became visible at 6:45 p. m. while the moon was still above the horizon. We observed it chiefly between 9 and 9:20 p. m. when there were two practically complete and one or two partial arches at various heights covering the northern one-third of the sky. The chief activity was in the northeastern quadrant of the sky where rays showed up nearly to the zenith. In the west a few streamers gathered weakly into half a corona. The display lasted at least until 10 p. m. but was not observed in any detail after 9:30 p. m.

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CHARLES F. BROOKS

RADIO FADE-OUTS AND THE ASSOCIATED MAGNETIC VARIATIONS

1—The recent papers on "Sudden disturbances of the ionosphere", by J. H. Dellinger[1], and on "Terrestrial-magnetic and ionospheric effects associated with bright chromospheric eruptions," by A. G. McNish[2], unfold a fascinating chapter of recent research in solar and terrestrial physics. The general course of their arguments and conclusions seems to me altogether convincing. The chromospheric eruption sends out an intense and fleeting pulse of ultra-violet light, whose main ionizing effect in the Earth's atmosphere occurs below the E-layer, over the sunlit hemisphere only; the dynamo-electric forces which are always present throughout the atmosphere are thereby given enhanced scope, and produce electric current-flow in the region of new or intensified electric conductivity; the ordinary S_q (where S_q signifies the quiet-day solar-diurnal magnetic variation) current-system and its S_q magnetic field are thus suddenly augmented over the sunlit hemisphere, until the increased ionization, which causes pronounced radio fading, dies away owing to the rapid recombination which must occur in that region of relatively high density and short free paths.

2—The two authors quoted show clearly that this type of magnetic variation is quite distinct from the variations ordinarily known as magnetic disturbance. Dellinger rightly emphasizes the need, in studying the "radio fade-out" type of magnetic variation, to consider the results observed at a number of places, in order to be sure that an effect apparently of this type is really so. He regards the discovery of a separate type of terrestrial-magnetic disturbance, with remarkable characteristics which clearly differentiate it from magnetic storms or any previously known types of magnetic perturbations, as one of the major results of the new researches (*loc. cit*, p. 130).

3—The object of this Note is to point out that Birkeland had already recognized this distinct type of perturbation, and many of its characteristics, in his great book on magnetic storms.[3]

4—In that work he classified magnetic disturbance under five heads, namely: (1) Positive equatorial perturbations; (2) negative equatorial perturbations; (3) positive and (4) negative polar elementary storms, and (5) cyclo-median storms. He regarded these five types as distinct, but nevertheless as having a certain connection with one another, for he supposed that they were all caused by electrons emitted from the Sun and deflected in various ways in the Earth's magnetic field. But he seems not to have realized fully that a great magnetic storm is a unitary phenomenon, going through regular phases, nor that weak storms or disturbance have the same average type of field, only less intense. This seems established by the analysis of disturbance according to storm-time and local time[4, 5, 6]. To me it seems clear that Birkeland's positive equatorial storm corresponds to the first phase of the non-polar part of a magnetic storm, and his negative equatorial storm to the second, major, phase. (He recognizes that negative equatorial storms can be more intense than positive ones; he found only a few negative equatorial

[1] J. Res. Bur. Stan., **19**, 111-143 (1937).
[2] Terr. Mag., **42**, 109-122 (1937).
[3] K. Birkeland, Norwegian aurora polaris expedition, 1902-1903, **1**, Chapters 2, 3 (1908).
[4] N. A. F. Moos, Colaba magnetic data, 1846-1905, **2** (1910).
[5] S. Chapman, Proc. R. Soc., A, **95**, 61-83 (1918).
[6] S. Chapman, Proc. R. Soc., A, **115** 242-267 (1927).

storms among his data, and since the changes during the major phase of a storm are slower and more gradual, the weaker the storm, it is natural that the negative perturbations occurring in his data—for a relatively quiet period—should not be conspicuous.)

His positive and negative polar storms and the associated current-systems agree with the average character of polar disturbance as outlined in studies of my own[6], [7]. Since his polar data covered only a limited area, only one of his special types of current-circuit was prominent in his data at any given time. His typical disturbances often extended over only a few hours, and rarely for as long as a day, whereas magnetic storms are often active for a day, and sometimes for much more. This is another indication that he split up the storm-fields artificially into portions that should really be considered as a whole.

Hence his first four types of storm appear to be only separate parts or aspects of one phenomenon, deserving when intense to be called a magnetic storm, but often appearing weakly (without marked individuality, beginning, or end), and then called general magnetic disturbance or activity. The whole phenomenon must be considered and explained as a unity, resulting from a single primary cause operating in different regions in different ways.

Birkeland's fifth type, the "cyclo-median storm," stands quite apart from the rest, as he clearly indicated. He gave only one distinct example, of date October 6, 1902. It was a mere fleeting disturbance of the magnetographs occurring on an otherwise quiet day—what is often called a bay. It lasted from $14^h\,13^m$ to $14^h\,48^m$, and affected declination and horizontal force simultaneously. An examination of his discussion, description, and charts indicates clearly, in my opinion, that it was a disturbance of the same kind as those discussed by McNish. It would be interesting to know whether any observations of a solar eruption on that day are on record.

It seems fair to say, therefore, that this distinct type of disturbance had already been recognized by a geomagnetician, Birkeland, long before the new techniques of radio and solar physics permitted the rapid elucidation of the phenomenon, which we have recently witnessed. It is somewhat remarkable that Birkeland's discovery was so long ignored by workers in terrestrial magnetism. Birkeland rightly concluded that this type of disturbance was produced by currents relatively near the Earth, but in other respects his theoretical views concerning it cannot be defended.

A discoverer is often accorded by his fellow-workers a right, or at least a preference, in the naming of his discovery. It seems to me that for this reason Birkeland's terminology for magnetic disturbance should be carefully considered, and should influence any attempts that may be made to arrive at an agreed usage. While his artificial dissection of magnetic storms renders it inadvisable to adopt his names as they stand, these might, I suggest, justify the naming of the first and second phases of a storm as the positive and negative phases. These names would be a reminder that they cover the periods during which the average horizontal force is respectively increased and decreased, and to my mind they are preferable to some of the names hitherto in use (impetus for the first phase, post-perturbation for the second).

[7]S. Chapman, Terr. Mag., **40**, 349-370 (1935).

I would, however, consider it unsuitable that either of Birkeland's words, "cyclo-median" or "storm," should be applied to the type of variation discussed by McNish and Dellinger. Subject to their views on the matter, it would seem to me best, and in accordance with their conclusions, to apply the name "S_q-augmentation" or "S_q-bay" to this type of variation.

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REMARKS ON DR. CHAPMAN'S NOTE ON RADIO FADE-OUTS AND THE ASSOCIATED MAGNETIC DISTURBANCES

It must be recognized that the special type of magnetic disturbance now known to be associated with radio fade-outs and bright chromospheric eruptions was discerned as a special type of disturbance in Birkeland's masterful treatise on magnetic storms. The disturbance on October 6, 1902, which he designates as a "cyclo-median storm," is clearly of this class. The writer overlooked this discovery because 18 of the 19 perturbations described by Birkeland were characterized by auroral-zone activity, and even the perturbation of October 6 was confused by representation of overhead currents at Axelöen, a high-latitude station. Birkeland's remarkable insight caused him to point out in the description of the disturbance that the current-flow over Axelöen was probably independent of that exhibited in low and middle latitudes.

Birkeland failed to recognize that the special disturbance, occurring on a quiet day, consisted of an augmentation of the normal quiet-day diurnal variation. This was first suggested by J. A. Fleming[1] and proved by the writer in the paper cited by Dr. Chapman. This proof was possible only by examination of data from a large number of observatories. It was rendered particularly cogent by the fact that at the time of fade-out on April 8, 1936, the normal diurnal variation at Teoloyucan was anomalous. Even this anomaly was reproduced by the disturbance associated with the fade-out. Realization that the special disturbance consisted of an augmentation of the normal diurnal variation and conclusions drawn from this realization constitute the significant contributions of the Department of Terrestrial Magnetism.

The writer agrees with Dr. Chapman that application of either of Birkeland's terms "cyclo-median" or "storm" to these special disturbances would be misleading. Dr. Dellinger refers to them as "magnetic pulses." This term fails to distinguish the effects from numerous other pulses which are frequently present on magnetic records. The writer has called them "solar-flare disturbances." It is suggested that this term be adopted because it at once indicates the genesis of the phenomena. It does not seem advisable to apply any term which associates the phenomena with the quiet-day diurnal variation unless it can be shown that if a solar-flare disturbance occurs during a magnetic storm the storm-field is not likewise enhanced. An investigation of this possibility is now in progress at the Department of Terrestrial Magnetism.

DEPARTMENT OF TERRESTRIAL MAGNETISM, A. G. MCNISH
CARNEGIE INSTITUTION OF WASHINGTON,
Washington, D. C., October 15, 1937

[1]Terr. Mag., 41, 404-406 (1936).

REMARKS ON S. CHAPMAN'S NOTE ON RADIO FADE-OUTS AND THE ASSOCIATED MAGNETIC DISTURBANCES

In Dr. Dellinger's absence from the United States I thank Professor Chapman for pointing out Birkeland's important, and partially neglected, contributions to the knowledge of the perturbations of the Earth's magnetic field. During the past two and one-half years ionospheric research by radio methods has contributed to the elucidation of the phenomena of solar and terrestrial physics with striking rapidity. A brief review of the recent impressive contributions of ionospheric research to these problems appears to be in order along with Chapman's review of Birkeland's work, and will show the fruitfulness of the radio methods. Dellinger[1] announced the radio fade-out as a semi-world-wide phenomenon, occurring on the illuminated hemisphere of the Earth, depending on some solar emanation lasting only a few minutes and with an apparent 54-day recurrence period. At Dellinger's[2] suggestion, Richardson[3] at Mt. Wilson, looked for and found visible solar eruptions coincident with the fade-outs of July 6 and August 30, 1935. Dellinger[4] next reported sudden changes in terrestrial magnetism, not associated with a magnetic storm, simultaneous with the fade-out of February 14, 1936, and sudden changes in terrestrial magnetism, earth-currents, and solar hydrogen eruptions simultaneous with the fade-out of April 8, 1936. With the exception of the earth-current changes, Richardson[5] reported similar observations for these same two dates, and Torreson,[6] Scott, and Stanton found all of these phenomena occurring simultaneously at Huancayo, Peru, on April 8, 1936. Dellinger's associate, Smith,[7] at first located the disturbed region of the ionosphere in the E-layer and Dellinger later located it below the E-layer. He[4, 8] also concluded that the effect was caused by electromagnetic radiation (that is, ultra-violet light) from the Sun and was most intense where the Sun's rays were perpendicular to the Earth's surface.

As McNish states in his letter of October 15, 1937, Fleming and McNish have shown that the magnetic variations accompanying radio fade-outs are an augmentation of the normal quiet-day variation. McNish has also plotted ionospheric current-systems which would produce the observed magnetic effects.

At the same time as these phenomena were being observed and elucidated, Dellinger's associates[9, 10] at the National Bureau of Standards, also using radio methods, were observing and reporting ionospheric perturbations associated with magnetic storms. They located these perturbations in the higher part of the ionosphere, principally in the F_2-layer, and showed that this part of the ionosphere was increased in height and diffused during these disturbances which lasted for periods of about a day or more.

The problems whose solution has been outlined above had been puzzling magneticians and geophysicists for many years. The elucidation of these problems by the methods indicated constitute an impressive achievement for ionosphere research by radio methods, which is an important tool which Birkeland and other magneticians have heretofore lacked.

National Bureau of Standards S. S. Kirby
Washington, D. C., November 30, 1937

[1]Science, **82**, 351 (1935).
[2]Science, **82**, 548-549 (1935).
[3]Science, **83**, No. 2141, Sup. 6-7 (1936).
[4]QST, **20**, 37-38 (1936).
[5]Terr. Mag., **41**, 197-198 (1936).
[6]Terr. Mag., **41**, 199-201 (1936).
[7]J. Wash. Acad. Sci., **26**, 479-480 (1936).
[8]Phys. Rev., **50**, 1189 (1936).
[9]Phys. Rev., **48**, 849 (1935).
[10]Phys. Rev., **50**, 258-259 (1936).

PRINCIPAL MAGNETIC STORMS

SITKA MAGNETIC OBSERVATORY
JULY TO SEPTEMBER, 1937[1]

(*Latitude 57° 03'.0 N., longitude 135° 20'.1 or $9^h 01^m.3$ W. of Gr.*)

July 6-7—A slight disturbance occurred on July 6, characterized by a sharp movement in *D* and *H* (76 gammas decrease in *H*) at $0^h 52^m$ GMT. The elements remained calm until 11^h at which time they began to decrease gradually until $14^h 30^m$ GMT, then started a slow but steady return to normal values. The trace was at its normal value about 03^h GMT, July 7. The disturbance was marked by its uniform motion; sudden rapid oscillations were noticeably absent. Ranges: *D*, 31'; *H*, 211 gammas; *Z*, 331 gammas.

July 22—A slight disturbance started suddenly at $07^h 24^m$ GMT, July 22, after about six hours of small fluctuations. The disturbance lasted until 11^h when the elements gradually returned to normal. By 13^h the trace was only slightly irregular. The disturbance was characterized by large short-period fluctuations of 250 to 300 gammas in *H* and *Z* and 40' in *D* in intervals of four to five minutes. Ranges: *D*, 85'; *H*, 772 gammas; *Z*, 690 gammas.

August 2-3—A slight disturbance started gradually at $03^h 40^m$GMT, August 2, then until 5^h the activity increased steadily. From 5^h to $11^h 20^m$ the disturbance was at its maximum intensity, with large fluctuations of the elements in a relatively slow-period motion. The traces then started a gradual recovery to normal values. However at $13^h 50^m$ there was a sudden burst of activity of short-period oscillations lasting about an hour. At $14^h 20^m$ there occurred a sudden decrease of 360 gammas in *H* in ten minutes; the other elements (*D* and *Z*) showed only an increased activity during this interval with no large change of ordinate. From $14^h 30^m$ GMT, August 2, until 05^h GMT, August 3, the elements were quite agitated, vibrating continuously with a two- to three-minute period and amplitude of 15 to 25 gammas. The general trend during this interval was toward normal values, the short-period motion gradually fading out. By 05^h the elements had returned to normal. Ranges: *D*, 147'; *H*, 985 gammas; *Z*, 605 gammas.

August 22—After about two weeks of comparatively quiet magnetic conditions, a moderate storm began abruptly at $03^h 07^m$ with a characteristic sudden movement of about 65 gammas in *H* and corresponding changes in the other elements. The disturbance increased gradually in intensity until 5^h GMT, when the elements were quite disturbed. The storminess increased slightly to maximum intensity at 10^h. The storm ended at 14^h GMT, however the trace remained slightly disturbed until 24^h. Ranges: *D*, 153'; *H*, 1310 gammas; *Z*, 840 gammas.

ROBERT E. GEBHARDT, *Observer-in-Charge*

[1]Communicated by R. S. Patton, Director, United States Coast and Geodetic Survey.

Cheltenham Magnetic Observatory
July to September, 1937[1]

(Latitude 38° 44′.0 N., longitude 76° 50′.5 or $5^h\,07^m.4$ W. of Gr.)

July 9-10—A mild disturbance began abruptly, but with small displacements, at $11^h\,43^m$ GMT, July 9. It ended at 10^h, July 10. Ranges: *D*, 27′; *H*, 128 gammas; *Z*, 45 gammas.

July 13-17—A mild disturbance began at 18^h GMT, July 13. The disturbed condition lasted several days to the end of July 17. The perturbations were irregular with no outstanding peculiarities. The greatest ranges occurred on July 14 and were: *D*, 31′; *H*, 157 gammas; *Z*, 85 gammas.

July 18-27—The field was again perturbed from July 18 to 27. During this time there were short-period oscillations, sometimes superimposed on long-period oscillations. The disturbances were not severe except during the first half of July 24, when the ranges were: *D*, 38′; *H*, 128 gammas; *Z*, 102 gammas.

August 1-2—A storm began with a sudden commencement in *H* at $21^h\,50^m$ GMT, August 1. *H* decreased 9 gammas the first minute, then increased 38 gammas in three minutes; the shifts in *D* and *Z* at the beginning were small. All three elements were moderately disturbed with irregular oscillations until 5^h, August 2, when long-period oscillations began and continued to the end of the disturbance at 11^h, August 2. The storm was characterized by large ranges in *D* and *Z*. Ranges were: *D*, 63′; *H*, 185 gammas; *Z*, 259 gammas.

August 21-23—A sudden commencement occurred at $21^h\,11^m$ GMT, August 21, when *H* decreased 6 gammas then almost immediately increased 33 gammas in six minutes. *H* then decreased gradually to its normal value in about one and one-half hours and remained quiet until $03^h\,08^m$, August 22, when there was another sudden increase of 54 gammas in three minutes. The storm at this time became severe, the more violent portion occurring between 07^h and 14^h, August 22. The commencements of *D* and *Z* at $21^h\,11^m$, August 21, were small but discernible and these two elements were not disturbed until the second commencement at $03^h\,08^m$, August 22, when they, too, attained storm-proportions. After 14^h, August 22, there were short-period oscillations of small amplitude until the end of the storm in the third hour of August 23. Ranges: *D*, 69′; *H*, 344 gammas; *Z*, 454 gammas.

September 10-11—A mild storm began at $17^h\,50^m$ GMT, September 10, and ended gradually about 20^h, September 11. It was characterized by a rapid decrease of 120 gammas in *H* at $22^h\,29^m$, September 10. At the same time *D* and *Z* decreased less rapidly by 5′ west and 16 gammas, respectively. Ranges: *D*, 27′; *H*, 181 gammas; *Z*, 129 gammas.

September 30-October 1—A mild disturbance began suddenly at $13^h\,45^m$ GMT, September 30, with an abrupt increase of 29 gammas in *H*. The changes in *D* and *Z* at this time were small but noticeable. There were short-period pulsations superimposed on irregular oscillations until midnight of October 1. Ranges: *D*, 31′; *H*, 144 gammas; *Z*, 118 gammas.

Albert K. Ludy, *Observer-in-Charge*

[1]Communicated by R. S. Patton, Director, United States Coast and Geodetic Survey.

Tucson Magnetic Observatory
July to September, 1937[1]

(Latitude 32° 14′.8 N., longitude 110° 50′.1 or $7^h 23^m.3$ W. of Gr.)

July 19-26—A sudden increase of 42 gammas in *H* occurred at $12^h 53^m$ GMT, July 19, and was followed by a prolonged period of disturbance. For two days the disturbance consisted chiefly of short-period oscillations of *H* and *D*, the latter being of small amplitude. By 13^h, July 21, the disturbance appeared to have ended. But about 18^h the fluctuations began again very gradually, accompanied this time by a slowly decreasing value of *H*. At 07^h, July 22, there began a series of irregular large movements, which continued with varying intensity for a little more than three days. The minimum of *H* for the storm occurred at $1^h 51^m$, July 24. By $03^h 28^m$ *H* had increased 122 gammas, this being the largest change in an equivalent interval during the entire period. The disturbance died out very gradually, ending about the middle of July 26.

August 1-4—This disturbance appears to have been two storms, but they were separated by such a short interval that they will be treated as one.. At $21^h 49^m$ GMT, August 1, *H* increased sharply about 15 gammas, but this was followed by only slight activity for about five hours. Then came a number of relatively large bays in all the elements. These were followed by a greatly depressed value of *H*, but otherwise the activity was moderate. *H* gradually recovered, and by 12^h, August 3, all the traces were practically normal. At $22^h 30^m$, August 3, there was another sharp beginning, followed by a number of shallow bays and by moderate short-period activity during the next 12 hours. Except for a slightly depressed *H*, the traces became normal at 10^h, August 4.

August 22-23—This storm began sharply at $03^h 08^m$ GMT, August 22, with an increase in *H* of 41 gammas. An hour later *H* began to decrease rapidly, reaching its lowest value at $09^h 12^m$, the change from the high value at the beginning of the storm being 216 gammas. While *H* was decreasing, and for several hours afterward, *H* and *D* executed a number of moderately large bays, as well as smaller oscillations. At 14^h, the oscillations ceased rather abruptly, though *H* was still far below normal, and did not fully recover for another 24 hours.

September 10-11—From 18^h GMT, September 10, to about 13^h, September 11, the traces were decidedly disturbed though not violently. The outstanding feature of the storm was a drop in *H* of 84 gammas in four minutes, beginning at $22^h 26^m$, September 10. At the same time east declination increased 8′. Otherwise the disturbance consisted chiefly of large bays.

September 30-October 2—At $13^h 45^m$ GMT, September 30, *H* suddenly increased 26 gammas; east declination and *Z* also increasing slightly. There was no further activity of importance until 16^h Then *H* began to decrease rapidly for about nine hours, the change in this period being 144 gammas. The decrease was accompanied by minor short-period oscillations in *H* and *D*, and was followed by a series of long, shallow bays, mostly in *H*. The disturbance ended about 2^h, October 2.

John Hershberger, *Observer-in-Charge*

[1]Communicated by R. S. Patton, Director, United States Coast and Geodetic Survey.

Huancayo Magnetic Observatory
July to September, 1937

(Latitude 12° 02′.7 S., longitude 75° 20′.4 or 5^h 01^m.4 W. of Gr.)

July 9—At 11^h 44^m GMT, July 9, there was a sudden commencement with small increases in D, H, and Z.

July 11—At 14^h 53^m GMT, July 11, there was a sudden commencement with small increases in D, H, and Z.

July 14—Between 16^h 46^m and 17^h 03^m GMT, July 14, a sharp decrease and subsequent increase in H occurred. The minimum value of H at 16^h 53^m was 29428 gammas.

July 19—At 12^h 55^m GMT, July 19, there was a sudden commencement in all three elements. H increased 17 gammas, decreased 11 gammas, and then increased 56 gammas in five minutes. D increased 2′ and Z increased 8 gammas in the same interval. The traces were moderately disturbed following this commencement.

August 21—At 21^h 13^m GMT, August 21, a sudden commencement occurred with effects in D and Z, and an increase of 16 gammas in H in three minutes.

August 22—At 03^h 08^m GMT, August 22, a sudden commencement occurred involving a decrease of 2′ in D, an increase of 7 gammas in Z, and an increase of 45 gammas in H in a period of four minutes. The traces were disturbed for the twelve hours following this commencement.

August 28—At 19^h 26^m GMT, August 28, there was a sudden increase in H and a simultaneous increase began in both D and Z. There was a fade-out in the ionospheric trace between 19^h 26^m and 19^h 57^m.

September 10—At 17^h 53^m GMT, September 10, a sudden commencement occurred in all three elements and H increased 77 gammas in three minutes. The traces were disturbed until 19^h on September 11.

September 30—At 13^h 46^m GMT, September 30, a sudden commencement began in all three elements. H decreased 34 gammas in one minute and increased 165 gammas in five minutes. The effects in D and Z were much smaller. The traces were very disturbed for the rest of the day. Radio fade-outs of intensity three occurred during the magnetic disturbance and the earth-current record was highly disturbed. Clouds prevented good spectrohelioscopic observations.

Frank T. Davies, *Observer-in-Charge*

Watheroo Magnetic Observatory
July to September, 1937

(Latitude 30° 19′.1 S., longitude 115° 52′.6 or 7^h 43^m.5 E. of Gr.)

July 19—There was a sudden commencement on July 19 at 12^h 53^m 50^s GMT. D moved easterly 1′ and returned to normal in two minutes of time. Then after an interval of twelve minutes a slow westerly movement began, the total change being 4′ in the following fourteen minutes. H increased 27 gammas in four minutes, then remained high and undisturbed. The numerical value of Z abruptly decreased 6 gammas, then increased 4 gammas, followed by a slow decrease of 15 gammas over twelve minutes and an increase of 20 gammas

over fifteen minutes. The character of the trace was "1" for several hours.

July 23-26—There was a sudden commencement at $05^h\ 01^m$ GMT, July 23. *D* moved westerly 1′ in two minutes, then easterly 2′ returning to normal at $05^h\ 11^m$. *H* increased 10 gammas in five minutes then slowly fell off 35 gammas in an hour. The numerical value of *Z* increased 4 gammas in two minutes followed by a decrease of 12 gammas in the next six minutes. Disturbed conditions prevailed up to midday July 26.

August 22—This storm began with a sudden commencement at $03^h\ 06^m\ 25^s$ GMT, August 22. *D* moved westerly 1′.5 in one minute, *H* increased 22 gammas in five minutes, and the numerical value of *Z* decreased 4 gammas then increased 9 gammas in two minutes. Minima in *D*, *H*, and *Z*, occurred at $09^h\ 42^m$, $09^h\ 53^m$, and $07^h\ 20^m$, respectively. Maxima in *D* and *H* occurred at $12^h\ 37^m$ and $03^h\ 13^m$. The maximum in *Z* was not recorded, the spot being off the trace for 1¾ hours. The storm ended at 22^h. Ranges: D, 24′.7; *H*, 325 gammas.

September 30-October 1—There was a sudden commencement at $13^h\ 46^m$ GMT, September 30. *D* moved easterly 1′ in one minute followed by disturbed conditions and gradual westerly movement of 10′ in four hours. *H* increased 2 gammas and decreased 5 gammas in two minutes followed by an increase of 22 gammas during the next two minutes. The numerical value of *Z* abruptly decreased 5 gammas followed by a further decrease of 7 gammas in eight minutes. Moderate storm-conditions prevailed till 14^h, October 1, accompanied by ionospheric and earth-current disturbances. Ranges: *D*, 15′; *H*, 175 gammas; *Z*, 145 gammas.

J. W. GREEN, *Observer-in-Charge*

REVIEWS AND ABSTRACTS

E. V. Appleton, R. Naismith, and L. J. Ingram. *British radio observations during the Second International Polar Year 1932-33*. London, Phil. Trans. R. Soc., A, v. 236, 1937 (191-259).

The material presented in this report constitutes a comprehensive survey of the ionospheric studies made principally at Slough, England, and Trömso, Norway, under the auspices of the Radio Research Board of the British Department of Scientific and Industrial Research. The experimental methods, observations, and results for this period are organized in ten well-catalogued sections followed by a summary of conclusions. There is also included a smattering of subsequent observations at Slough, which is necessary to elucidate points under discussion. While the report as a whole is of unusual interest, workers in this field will find the complete collection of experimental observations especially welcome.

In the first five sections are briefly outlined the organization of the program and the description of the apparatus. They form the background before which the experimental facts can be interpreted and assessed. The essence of the report is contained in sections 6 to 10 in which are presented an outline of the nature of the problem and the experimental data and their discussion. The observations are most completely represented in graphical form—it is to be somewhat regretted that tabular presentation was not made more frequently; because the investigator who would use the data for further study must prepare tables from the graphs: Judging from the comprehensive character of some 27 graphs of experimental material, most of the observations made during the period can be found in the report.

The observations are discussed particularly with regard to their bearing on the assumption of normal layer-formation by ultra-violet light, and their relation to magnetic activity. Except for parts of these discussions, analytical methods are avoided, resort being made to graphical comparison in most cases. An especially important contribution is the subdivision of the data according to season in derivation of correlation-coefficients between ionization of the ionospheric regions and magnetic activity. The result, that the correlation-coefficient undergoes a change of apparent significance with season (with especial regard to the F_2-region) will be consoling to investigators who have not succeeded in finding a simple generalized relation between layer-ionization and magnetic activity, though this is not explicitly included in the conclusions.

The report is especially rich in suggestions regarding various phenomena and proposals concerning their physical mechanisms. While the conclusions are necessarily restricted by the available data, there are indicated a number of new effects, found especially in the polar regions, which should be worthy of further investigation.

L. V. Berkner

D. C. Rose: *The atmospheric potential-gradient at Ottawa, Canada*. Canad. J. Res., Ottawa, A, v. 15, 1937 (119-148).

The paper presents a discussion of potential-gradient observations made on the north side of the City of Ottawa during the twelve months from December 1, 1934, to December 1, 1935, and of observations made at a station in the country nine miles northwest of Ottawa from June 26 to November 3, 1936. The potential-gradient data are studied particularly in relation to air-mass movements or "fronts," and seven cases illustrative of disturbed potential-gradients associated with "fronts" are presented in detail, the variations in barometric pressure being given together with descriptive weather-notes and reproductions of weather-charts.

In the first part of the paper the locations of the two observing stations are described, with a view to informing the reader as to the effect local pollution might have on the potential-gradient values. The conclusion seems fairly drawn that both locations in the city and country are favorably situated for minimum difficulty with pollution.

In the next few pages the apparatus is described; the same apparatus, with minor changes, was used at both stations. The details given indicate that proper consideration was given to the important matter of insulation and that maintenance of the apparatus at high operating efficiency was attained through regular inspections and adequate control-observations. A factor for reducing observed potentials to values representative of an open, level plain was not obtained for the station in the country and was only

roughly deduced for the other station because the potential-gradient in volts per meter was not needed for the discussion of the results of chief importance in the paper.

Undisturbed "fair-weather" observations were obtained in the city only one-fourth of the time during the year of observation and in the country about three-fourths of the time during four months, so the monthly mean diurnal-variation curves for the city are less smooth than are those for the country. The curves are in general agreement with those obtained at most similarly situated stations throughout the world. The curves for the station in the country, less affected by pollution than those for the city, have their maximum close to 14^h (75th west meridian time), in good agreement with the universal 24-hour wave found by Mauchly from *Carnegie* data.

The latter half of the paper is devoted to discussion of the seven occasions showing potential-gradient disturbances at the passage of a "front." Four of these were obtained at the station in the country, three at the station in the city. The author points out that to separate out the effects of rain, thunderstorm, and the generally increased mixing by turbulence with a "front," would require much more detailed meteorological observation than was possible. The author concludes however that the passage of a "front" coincided with 26 out of 42 disturbances noted at the station in the country and that nine others would have been found to coincide had the meteorological notes been adequate. For the city it was concluded that pollution caused some of the disturbances found, and this is discussed in the final paragraphs of the paper.

The reader is led to the conclusion that air-mass movements or "fronts" are basically responsible for potential-gradient disturbances except in those cases where pollution is at times sufficiently plentiful to be responsible. While this may be true, perhaps, for Ottawa and surrounding territory, and for many other places as well, there are undoubtedly many regions as, for example, in mountainous country or over arid or semi-arid plains or plateaus, where heavily charged clouds do form without the presence of a "front" and where these clouds cause great disturbances in potential-gradient, though rains and thunderstorms may or may not occur within sight of the potential-gradient station.

Care is taken throughout the paper to indicate where scarcity, incompleteness, and uncertainty of data make it impossible to draw definite conclusions about various phases of the work; this is in keeping with the experience of most investigators in atmospheric electricity, for the various atmospheric-electric elements are influenced by so many factors that their proper study can only be made with more time, effort, apparatus, and personnel than have been generally available in the past.

It is perhaps worthy of note that, although the study of potential-gradients associated with meteorological disturbances was the primary object of this investigation, the potential-gradient apparatus was adjusted to operate best under "fair-weather" conditions and record was generally lost during disturbed periods. Though the loss of record was not serious for the discussions of the present paper, too much emphasis has been laid until now by most investigators on fair-weather observations; it is becoming increasingly evident that equal emphasis must be placed on both fair-weather and bad-weather measurements and that instruments must be devised to meet adequately the demands encountered under all conditions of weather in order that the major problems of atmospheric electricity may be solved.

In the presentation of his investigations of atmospheric potential-gradient in relation to periods of meteorological disturbance, the author has made an interesting contribution to that aspect of atmospheric electricity which most needs investigation and discussion.

O. W. Torreson

J. A. Fleming (Editor): *Transactions of the American Geophysical Union; Eighteenth annual meeting, April 28, 29, 30, 1937, Washington, D. C., Regional meeting, June 21 to 26, 1937, Denver, Colorado.* Washington, D. C., National Research Council, July, 1937 (663 with illus.). 25 cm.

The Transactions of the eighteenth annual meeting of the American Geophysical Union are published in two sections: Part I contains reports and papers presented at the meetings in Washington (General Assembly, and sections of Geodesy, Seismology, Meteorology, Terrestrial Magnetism and Electricity, Oceanography, and Volcanology); Part II contains the reports and papers of the Section of Hydrology presented at its sessions in Washington, D. C., and Denver, Colorado, and its joint meeting at the latter place with the South Continental Divide Snow-Survey Conference.

At the sessions of the seven sections held at Washington, D. C., April 28-30, 1937, progress-reports on their several departments of geophysical work were as a rule presented in addition to the numerous scientific papers.

The scientific session of the General Assembly was devoted to a symposium on theoretical and observational considerations of importance to further studies of the depths of the Earth. The five papers presented dealt with the estimation of temperatures at moderate depths in the Earth's crust; the external gravity-field and the interior of the Earth; deep-focus earthquakes and their implications; the Earth's interior as inferred from terrestrial magnetism; and the behavior of matter under extreme conditions. At this session, detailed reports were received from two special committees, namely (1) on geophysical and geological study of oceanic basins and (2) on geophysical and geological study of continents.

The papers presented at the session of the Section of Terrestrial Magnetism and Electricity are of particular interest to the readers of this Journal and include the following: The 23-, 46-, and 92-year cycles in solar and terrestrial phenomena, by C. G. Abbot; Radio balloon-measurements of the cosmic radiation, by T. H. Johnson; Geographic asymmetries of cosmic rays as related to the Earth's magnetization, by M. S. Vallarta and W. P. Jesse; Report of Committee on Dissemination of Magnetic Data of American-operated Observatories, by E. O. Hulburt, S. S. Kirby, A. K. Ludy, and A. G. McNish; Earth-current variations with periods longer than one day, by W. J. Rooney; An astatic magnetometer for measuring the susceptibility of materials for magnetic instruments, by E. A. Johnson and W. F. Steiner; A zero distribution-coefficient for horizontal-intensity magnetometers, by Geo. Hartnell; On the ionization of the F_2-region, by W. M. Goodall; A study of sudden disturbances of the ionosphere, by J. H. Dellinger; An investigation of the relation between bright chromospheric eruptions and fade-outs of high-frequency radio transmission, by R. S. Richardson; Radio fade-outs associated with bright chromospheric eruptions, by A. G. McNish; World-wide changes in potential gradient, by G. R. Wait and J. W. Mauchly; A new approach to the study of terrestrial-solar relationships, by J. W. Mauchly; Instruments and technique for continuous triangulation upon a sounding-balloon, by Brian O'Brien and H. S. Stewart, Jr.

In addition to the scientific papers, reports were received on magnetic and electric work of numerous organizations in North America during 1936-37. These included the United States Coast and Geodetic Survey, National Bureau of Standards, Universities of North Carolina, Rochester, and Alaska, Dominion Observatory, Massachusetts Institute of Technology, and the Department of Terrestrial Magnetism of the Carnegie Institution of Washington. The report of the Secretary of the Section contained a brief summary of the chief work accomplished at the Edinburgh Meeting of the International Association of Terrestrial Magnetism and Electricity. The importance of the newly inaugurated weekly compilations of magnetic character-numbers as determined from seven American-operated observatories and of the establishment of the San Miguel Cosmo-physical Observatory in Argentina, was pointed out. On the whole these reports bear witness to the continued wide-spread interest and the important work in geophysics of a large number of organizations in North America.

The two parts of these Transactions, containing a total of 663 pages, form a well-edited stately volume. It was, like the volumes of other Transactions in recent years, economically produced by the planographic method. In the present case a better quality of paper has been used resulting in clearer print and a more pleasing appearance. The volume represents another step in the steady advance of geophysics in America and will be indispensable to all who desire to keep abreast of the ever-widening research in that science.

H. D. Harradon

NOTES

27. *Work of the International Commission of the Polar Year 1932-33*—At the meeting of the International Meteorological Committee at Salzburg, in September, 1937, Dr. D. la Cour, President of the International Commission of the Polar Year 1932-33, presented a progress-report on the work accomplished since the last meeting in Warsaw in 1935. During this interval, the Commission has lost by death two of its members, namely, Professor L. de Marchi of Italy, and Professor A. Karpinsky of the U. S. S. R., both of whom took an active part in forwarding the work of the Commission.

The chief efforts of the Commission since 1935 have been to advance the discussion of the observations made during the Polar Year. In this connection, archives and documentations have been formed at Copenhagen, consisting of published discussions and photographic copies of registrations, which are made available to investigators for use in their studies. The collection of the films of magnetic registrations is particularly well advanced and copies of over 700 have been deposited at the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, in accordance with Resolution XII passed at the meeting of the Commission at Copenhagen in 1933. It was pointed out that the value of these archives does not consist alone in the present use but as well in their preservation for reference in connection with the organization of future projects in the nature of the Polar-Year enterprise.

The publication of synoptic weather-maps of the Northern Hemisphere during the Polar Year has been begun and the Commission now has in view the project of preparing a monograph on the weather in the Southern Hemisphere and texts and discussions pertaining to the synoptic maps of the Northern Hemisphere as well as tables of the aerological observations made during the Polar Year.

The report closed with a statement as to the present disposition of the meteorological and magnetic instruments belonging to the Commission with the indication that the magnetic instruments still available will be used for amplifying the results already obtained during the Polar Year (as, for example, the further investigation of the remarkable frequency of giant pulsations in Iceland) or for assisting in the establishment of magnetic stations in regions where greatly needed.

The President made clear that the Commission considers that its principal duty now is to push energetically the discussion of the Polar-Year data which have been collected not for the purpose of accumulating material but of advancing our knowledge of the natural phenomena of the Globe.

28. *Giant pulsations in Iceland*—In connection with the investigation of giant pulsations in Iceland, two stations for quick-run magnetic registration have now been established near Reykjavik about 15.5 kilometers apart. Some delay in mounting the instruments was occasioned by custom formalities and very rainy weather. Records have been obtained since July 28, at first with one needle only for the purpose of determining whether giant pulsations occurred. It was not, however, until August 2 and 7, that the two stations were completely established and all adjustments of the needles made.

29. *Dr. Wilhelm Filchner's Expedition in Asia*—Dr. Wilhelm Filchner was awarded, September 7, 1937, one of the three German National Prizes for Art and Science (of 100,000 Reichsmark each, awarded annually, for the first time in 1937), in recognition of his various scientific expeditions since 1900. He is known to the readers of this JOURNAL by his expedition of 1926-28, mainly devoted to magnetic measurements in China and Tibet; these were reduced by O. Venske (see review in this JOURNAL **36**, 253, 1931). He started on a new expedition in 1936, but was made prisoner early in 1937 when he entered Chinese-Turkestan and was released not before August.

30. *Swider Magnetic Observatory*—In February, 1936, a new adjustment of the vertical-intensity variometer at the Swider Magnetic Observatory, was undertaken. A comparison of the present values of vertical intensity with those already published indicates that it will be necessary to apply certain corrections which will change some of the hourly values without affecting the mean annual, monthly, and diurnal values. These corrections will be published as soon as possible.

31. *Notes regarding the magnetic observatories of the United States Coast and Geodetic Survey*—Regarding the immediate demands of the geophysical prospector and the investigator for the data of the magnetic observatory, the Tucson Magnetic Observatory furnishes telegraphic notice of the beginning and ending of magnetic storms to numerous organizations. This Observatory also furnishes blue-prints of the daily magnetograms to two organizations. The Cheltenham Magnetic Observatory, in addition to furnishing the daily magnetic character-figure for the Ursigram, also furnishes copies of its magnetograms to two organizations.

In accordance with Resolution No. 3 concerning the control of variometers, presented at the Edinburgh meeting of the Association of Terrestrial Magnetism and Electricity of the International Union of Geodesy and Geophysics, in September, 1936, the following instrumental improvements have been made at the Cheltenham Magnetic Observatory: The Eschenhagen *D*-variometer has been oriented accurately in the magnetic meridian and is free from torsion when the magnet is pointing in the direction of the mean for the day. Its orientation has been tested by magnetic methods and found to be satisfactory. The Eschenhagen bifilar *H*-variometer has been oriented accurately to the magnetic prime-vertical and also has been tested by magnetic methods. The Eschenhagen *Z*-variometer magnet has been tested for position and found to be essentially horizontal. The Adie *Z*-variometer has been overhauled and adjusted to a scale-value of about 10 gammas per millimeter and will be operated hereafter as an insensitive instrument.

An auxiliary observatory for use in making simultaneous absolute observations with two sets of magnetic instruments by two observers has recently been constructed on the grounds of the Honolulu Magnetic Observatory. The new building is of non-magnetic construction throughout and the observing-pier is centered precisely over the point that has been used for many years as an auxiliary station.

32. *Modification of daily American Ursigrams November 1, 1937*—There will be a change in the period covered by the daily American Ursigrams as regards the magnetic portion of these messages from the Cheltenham Magnetic Observatory, which in the past have referred to the period ending 8 a. m., 75° west meridian time, on the date specified, but hereafter will apply to the period ending 7 p. m. on the date specified. The purpose of this change is to make the messages cover exact Greenwich days. In making the change it was necessary to prepare two messages for November 1, 1937, one by the former scheme to extend from 8 a. m., October 31, to 8 a. m., November 1, and the other by the new rule to extend from 7 p. m., October 31, to 7 p. m., November 1. This second message was supplemented with the explanation "*This and all succeeding messages apply to Greenwich days.*" There is no change in the significance of the code numerals which have always been expressed in terms of Greenwich Mean Time and will so continue.

33. *Personalia*—Prof. Dr. *Friedrich Errulat* of the University of Königsberg, has been appointed Professor of Geophysics and Terrestrial Magnetism at the University of Hamburg.

Captain *Georges M. Horsch* has been appointed Director of the National Observatory of Athens, Greece.

W. E. Scott, who has been observer on the staff of the Huancayo Magnetic Observatory for three years, returned to Washington October 13, 1937.

H. W. Wells left Washington September 1, 1937, to resume his duties as observer and radio engineer at the Huancayo Magnetic Observatory; en route he attended the Pan-American Aviation Conference in Lima, September 16-23.

Admiral *R. S. Paton*, Director of the United States Coast and Geodetic Survey, died November 25, 1937, aged 55 years.

LIST OF RECENT PUBLICATIONS

By H. D. Harradon

A—Terrestrial and Cosmical Magnetism

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